KOA HAOLE (*Leucaena glauca*)

Its Establishment, Culture and Utilization as a Forage Crop

M. TAKAHASHI AND J. C. RIPPERTON

Bulletin 100
UNIVERSITY OF HAWAII
AGRICULTURAL EXPERIMENT STATION

COVER: A wild koa haole pasture in Kona; excellent growth renewal produced by topping off the trunks of the koa haole.

KOA HAOLE (*Leucaena glauca*)

Its Establishment, Culture and Utilization as a Forage Crop

With Notes on Other Forage Legumes

M. TAKAHASHI, Junior Agronomist

J. C. RIPPERTON, Agronomist

Bulletin 100

UNIVERSITY OF HAWAII AGRICULTURAL EXPERIMENT STATION

HONOLULU, HAWAII, U.S.A. JUNE 1949

CONTENTS

INTRODUCTION

A large number of species of the Leguminoseae family are common to the tropics. Some tropical legumes have been used since antiquity for food and form a basic part of the native diet. Others have long been used as green manuring and cover crops in the culture of tea, rubber, and coffee. However, references to their use or value as forage crops are few. Finally, many legumes growing as a part of the natural or wild tropical vegetation are entirely unexplored as potential sources of animal forage.

Koa haole is in the latter category. Although it is widely distributed as a part of the natural vegetation in the East and West Indies, the Philippines, and Malay as well as the tropical parts of the Americas, India, and Africa, there are no records of its culture and use as a forage crop elsewhere. It was introduced into Hawaii before 1888, since Hillebrand (*19*) mentions it as being of frequent occurrence. It was not mentioned in local literature as a forage plant until 1915 (*25*) and not until 1929 was it again referred to (*34*). Its value as a grazing shrub in beef production gradually became recognized and many ranches have broadcast koa haole seed over their ranges. One dairy on Kauai planted a field of koa haole about 1934 and fed the plucked branches of the plant to dairy animals.

In 1939 the Hawaii Agricultural Experiment Station began preliminary experiments on the establishment or culture of koa haole as a soilage crop. During the early part of World War II, investigations were expanded and a number of dairies made sizable plantings as a safeguard against interruptions of shipments of protein concentrates.

This bulletin presents the results of these agronomic investigations. Other departments of the Station have investigated the chemical composition of the plant and its feeding value, and a summary of their results is included. The first section of the bulletin describes the plant, its chemical composition, and forage value. The second part, "Establishment, Management, and Utilization," presents, for the dairyman and rancher, recommended agronomic practices in the establishment and culture of koa haole as a soilage crop. In the third section a short discussion is presented on its use as a pasture forage. The section "Experiments on Cultural Practices" presents in detail the results of the various field experiments. The final section appraises the various forage legumes which have been tried in Hawaii, and their relative advantages and disadvantages in comparison with koa haole.

The present need of the dairy industry for the local production of a greater proportion of its total feed requirements is stressed. Many dairies in Hawaii, faced with rising costs of imported feed and of labor, are operating at a financial loss. Inevitably costs must be reduced or dairies will close. Forage legumes should play an important part in reducing the amount of feed imported.

BOTANY, USES, AND FORAGE VALUE

BOTANY

Koa haole is known in Hawaii by common names such as false koa, koa bush, ekoa, lili-koa, and haole koa. To avoid confusion, "koa haole" has been proposed as the official common name. Elsewhere in English-speaking countries it is called accepted scientific name. *Mimosa glauca* L. is a synonym which is no longer justified. The generic name *Leucaena* refers to the white flowers, and the specific name *glauca* to the bluish-white color of the foliage.

Leucaena glauca is a member of the Mimosa family. The genus *Leucaena* includes nine species, seven of which are native to tropical America and one to the Pacific islands. *L. glauca* is the only species found in Hawaii. The genus is closely related to the genera *Acacia, Mimosa,* and *Desmanthus.* As far as the writers are aware none of the other species of *Leucaena* is used for forage.

A botanical description of the plant follows.

Leaves: Bipinnate, 15 to 25 cm. long; rachises pubescent; pinnae 4 to 8 pairs; 5 to 10 cm. long; leaflets 10 to 15 pairs, leaflets linear-oblong, acute, inequilateral, 7 to 15 mm. long, and 3 to 4 mm. wide.

Stipules: Triangular, glabrous, about 15 mm. long.

Flowers: White, 100–180 flowers clustered in a globular head 2.5 to 3 cm. in diameter, solitary, axillary, long pediceled, about 4 cm. in length.

Seed pods: Thin, flat, strap-shaped, acuminate, 12 to 18 cm. long, 1.4 to 2 cm. wide, usually 15 to 60 per cluster; covered with fine hairs when young; 15 to 25 seeds per pod.

Seeds: Elliptic compressed, shiny brown, 3 to 4 mm. wide, 6 to 8 mm. long, and about 2 mm. thick.

Koa haole is a deep-rooted perennial shrub; it sometimes attains the size of a small tree, growing 20 to 30 feet high with a trunk over 4 inches in diameter. Its prolific seeding habit tends to produce dense thickets. Under such conditions the plant consists essentially of a straight-growing single central stem with practically no lateral branches. The stem is quite woody, smooth, and copiously covered with lenticels. In the wild state, heavy podding occurs once a year during the dry summer months.

USE OF KOA HAOLE ELSEWHERE

In the West Indies (*29*) the ripe seeds and young pods are occasionally eaten with rice. According to Ochse (*26*) varied but limited use is made of koa haole as a food crop in the Dutch East Indies. Practically every part of the plant is used in one way or another. The young pods, young leaves, and flower buds are used as vegetables. Mature but still succulent seeds are eaten with rice or are made into botok by mixing the seeds with grated coconut and fish or meat, wrapping the mixture in a banana leaf, and cooking. The dry seeds are eaten with rice after the seeds have been roasted and pounded into a fine powder. The seeds are sometimes used for adulterating coffee. Even the young seedlings are mixed with dry fish and grated coconut and eaten. In the Philippines (*28*) the species has been planted as a preliminary to reforestation in lands taken possession by cogon grass (*Imperata cylindrica*). In Malay koa haole is used for green manuring and as shade for young coffee trees. In Hawaii and elsewhere in the Central Pacific islands the Polynesians use the seeds for making all sorts of ornamental articles. The wood is of little value because of its small size and lack of durability but is the favorite wood for staking pole beans and certain cucurbits in the Territory.

In view of koa haole's high palatability and widespread use for forage in Hawaii, it seems strange that it is not used as animal feed in other parts of the tropics (*27*). Responses to numerous letters sent to research institutions in places where the plant is common, as well as conversations with visiting scientists from other countries, verify the fact that the species is not grown as a forage crop elsewhere and is not recognized as a plant of any particular forage value in the native pastures; in fact, there appears to be some mistrust of the crop as an animal feed.

HAWAIIAN INVESTIGATIONS ON THE FORAGE VALUE AND USE OF KOA HAOLE

The non-utilization and distrust of koa haole as an animal forage may result from the fact that it often causes a pronounced loss of hair when fed to non-ruminants. This phenomenon has been noted in Hawaii on horses, mules, donkeys, swine, rabbits, and experimental rats. Generally hair will again develop if the feeding of koa haole is discontinued. Prolonged feeding of sufficient quantities of koa haole, to the smaller animals at least, may cause death. Beef and dairy animals, however, show no ill effects, and this is probably true of all other ruminants. It is presumed that the toxic principle is destroyed in the rumen of the animal.

In view of koa haole's increasing importance in Hawaii, the Hawaii Agricultural Experiment Station investigated the chemical constituents which might cause the crop's depilatory action. It was first thought that it might be due to selenium, since this element when present in a plant in excessive amount causes loss of hair together with more serious and permanent effects on the health of the animal. Analyses of koa haole taken from several locations in the Territory showed no significant quantities of selenium (*3*).

Later research by Yoshida (*35*) identified the depilatory principle as mimosine ($C_8H_{10}O_4N_2$) which is also called leucenol, an alpha-amino acid possessing phenolic properties. Mimosine is present in the water-soluble fraction of the leaves

Figure 1. *Left:* Thicket of koa haole in the center background growing as tall as the surrounding eucalyptus trees. *Right:* Overly mature koa haole field.

and seeds. It was found that certain soluble iron compounds have the ability to counteract the toxic effects of mimosine when fed to rats, but the large amounts required would probably make their commercial use impractical. The highest percentage of mimosine in the vegetative part of the plant was found in the immature leaves, which contained nearly three times the amount found in the mature, lower leaves (*12*). Normally, the seeds contain more mimosine than the leaves; on the oven-dry basis, the respective mean percentages are approximately 7 percent and 4 percent. Apparently the environment in which the plant is growing has no great effect on the mimosine content in the seed, the maximum variation from wet to dry locations being from 6.22 to 9.35 percent mimosine on the oven-dry basis. The mimosine content in the young leaves of introductions of koa haole from eight different countries showed no appreciable deviation from that of the common Hawaiian strain except for one introduction from El Salvador, Central America; this contained about 30 percent less mimosine than the others. Indications are that mimosine in the fresh leaves may be relatively unstable at elevated temperatures; samples stored at 40° C. lost as much as 60 percent of their original mimosine (*13*).

It is common local experience that koa haole causes severe loss of hair and other disturbances in rabbits if fed as the principal forage. Bice (*8*) states that it should not exceed 10 percent of the total roughage fed. Ensilage made from koa haole had apparently the same effect on rabbits as the fresh material. Willett *et al.* (*11*), using 20 percent and 40 percent koa haole meal in the ration, noted a reduction in the number of litters born in comparison with those of rabbits fed 20 percent alfalfa meal. Similar breeding troubles were encountered with swine fed fresh koa haole *ad libitum.*

The feeding of dried koa haole leaves to poultry as a substitute for alfalfa meal has produced some rather startling results. Palafox (*14*) reports that the hatchability of fertile eggs was increased from 68.4 percent when fed 5 percent alfalfa meal to 85.6 percent when fed 5 percent koa haole meal. Dams fed koa haole meal produced chicks consistently heavier than chicks hatched from dams fed alfalfa meal; moreover, the mortality of the former at 2 weeks of age was consistently lower. Palafox (*14*) concludes that koa haole contains some factor (or factors) which is essential for good hatchability but which is not found or is lacking in sufficient quantities in alfalfa meal.

Henke reports (*15*) that at the end of a 2-year investigation to determine the effect on milking cows of continuous feeding of koa haole as the sole roughage, the reproductive efficiency of four cows on koa haole averaged 91.6 percent while that for the four control cows fed non-leguminous roughage was 94.3 percent, a negligible difference. Henke (*16, 17*) has conducted a series of milk production trials, comparing koa haole and Napier grass as the source of roughage. In one series, only pineapple bran and molasses were used to fortify the koa haole, the latter providing 96 percent of the protein fed. There was no significant difference in the milk production from the animals fed this ration and that from the control animals which were fed Napier grass and a concentrate ration containing 10.9 percent digestible crude protein. In other tests koa haole, supplemented with a concentrate ration containing 5.43 percent digestible crude protein, proved to be as good for milk production as Napier grass supplemented with a concentrate ration containing 11.25 percent digestible crude protein. Similar results were obtained when the milk cows were grazed on koa haole supplemented with a low protein concentrate ration as compared with the control lot fed with chopped Napier grass and the high protein ration. Henke concludes (*17*) that the actual saving of soybean meal averaged about 3 pounds per cow per day. In a 100-cow dairy this saving would amount to 4.5 tons of soybean meal per month. Koa haole converted into ensilage or a dried meal makes satisfactory forage.

The favorable results of these investigations are verified by the experiences of local dairymen. One dairyman on Kauai has been feeding koa haole as the sole source of roughage for at least 10 years. Two dairymen on Maui have been growing the crop and feeding it mixed with Napier grass for about 5 years, with satisfactory results. Reports that koa haole tainted the milk are apparently without basis, if the ordinary precautions used in the feeding of most legumes are followed: namely, withholding the feeding of the legumes 2 hours prior to milking and thoroughly chilling the milk.

Hawaiian beef ranchers first became interested in koa haole when they noted the preference of cattle for it and the fine condition of animals grazing in pastures containing large amounts of it. In recent years, koa haole has been widely planted on the open range as well as in prepared pastures. Interplanted with Guinea grass, it makes up some of the finest fattening paddocks in the dry zones. In one experiment, Henke *et al.* (*18*) secured gains up to 1.15 pounds per day in paddocks which contained a tall natural growth of koa haole and almost no grasses. Cattle browsing for a considerable period on pastures containing a large amount of koa haole have a distinct yellow fat instead of the usual white fat. As far as is known there has been no consumer objection to the yellow fat color.

ESTABLISHMENT, MANAGEMENT, AND UTILIZATION AS A SOILAGE CROP

The following sections present the main features of the establishment and management of koa haole, where it is planted and utilized primarily as a cut forage crop. The recommended procedures are based principally on a series of experiments conducted over a period of about 7 years. These experiments are presented in detail in a later section, but for the convenience of the practical grower or the casual reader the main results and recommendations are given here.

CLIMATIC AND SOIL REQUIREMENTS

Since koa haole is of common occurrence as a wild plant in Hawaii and has probably reached its ultimate distribution, one can judge its climatic requirements and limitations with fair accuracy. It grows best between the rainfall limits of about 25 and 65 inches per year. These limits include vegetation Zones B and C_1 (*30*). In Zone A, representative of the driest locations, the crop will not grow except in local depressions or valleys where water accumulates through seepage or runoff, or along the coastal flats where the deep-rooted plant can reach ground water. With irrigation, koa haole grows best in the hot climates of Zones A and B. With rainfall in excess of about 65 inches, the plant is seldom found except on steep slopes where runoff is rapid. Ranchers contend that in these higher rainfall areas animals do not like koa haole, a marked contrast to the animal preferences for the forage in the drier zones. This same phenomenon has been noted with other legumes (such as the pigeonpea) which are not well utilized by animals in the wet zones.

Koa haole is sensitive to temperature and likes hot weather. Wild stands seldom extend above the 500-foot elevation in the higher rainfall windward sections and above 1,000 feet in the drier leeward locations. Whereas a seedling will normally attain a height of 5 feet in 6 months of growth at sea level, a planting at Kekaha, Kauai, 1,500-foot elevation, grew to only 12 inches in height in 2 years. Occasional plants are found at 2,000 feet at Ulupalakua, Maui, but no one knows how long it took these plants to grow. It seems likely that 600 to 700 feet is the maximum elevation for planting the crop for cut forage.

This crop is adapted to a wide range of soil types. Using the U. S. Department of Agriculture's soil classification,[1] it is found as wild stands on the Puhi Family and the driest parts of the Haiku Family of the Ferruginous Humic Latosols, the Catana Family of the Regosols, the Wahiawa and the Lahaina Families of the Low Humic Latosols and many of the Alluvial soil types. It will also grow in the better drained parts of the heavy-textured soils of the Hydromorphic and gray Hydromorphic soil groups. Actual plantings of koa haole for soilage purposes have been made in five locations on Oahu, two on Kauai, and five on Maui on various of these soil groups.

A unique feature in the natural distribution of koa haole is its apparent preference for comparatively steep slopes and rocky phases. It is not uncommon to

[1]By permission of the Division of Soil Survey, U. S. Dept. of Agriculture; the soil classification report is now in the process of publication.

find a more vigorous growth there than on the adjoining normal soils. This is particularly true in locations of higher rainfall. Deep root penetration in the rocky phases of the dry zones and better drainage in the steep slopes of the higher rainfall zones may in part explain this behavior. Even the thin and eroded soil phases permit the establishment of this hardy plant.

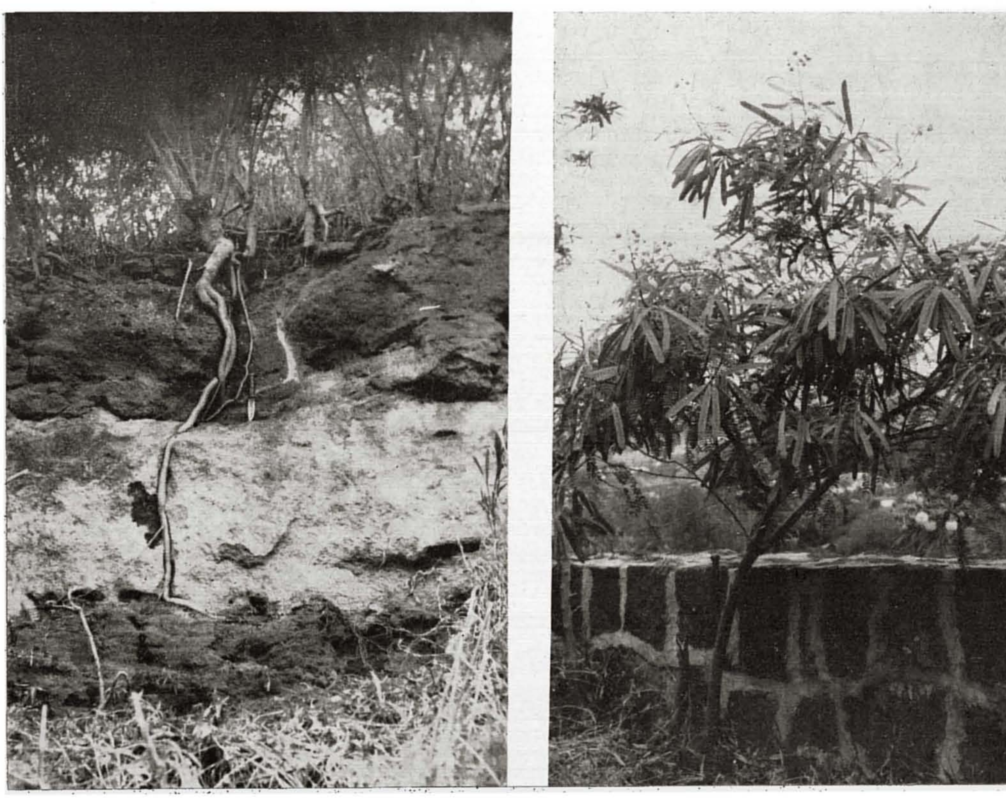
SEED AND PLANTING MATERIALS

Koa haole is commonly propagated from seeds, and the early growth is very slow. During the war, attempts were made to shorten the period from planting to the first cutting by the use of stem cuttings and stump plantings. The procedure, if successful, was expected to have the additional advantage of reducing the troublesome weeding problem associated with slower growing plants started from seeds.

The maximum stand obtained from stem cuttings was only 26.7 percent; germination was slow and growth poor. Stump plantings, that is, planting the crown and roots of various sized plants from wild stands, produced a nearly perfect stand and the initial growth was superior to that of seed plantings. Subsequent tests, however, showed that ratoon crops of the direct seeded plots were superior to those from the transplants. Direct seeding produced a greater forage yield over a 3-year period, and planting and weeding costs were materially lower. For practical purposes direct seeding is the only method that need be considered.

Seed can be readily collected from the many wild stands. The dry pods are gathered and the seeds threshed out, or separated by placing the pods loosely in a sack and beating the sack with a piece of board about the size of a small bat. Seeds

Figure 2. ***Left:*** **Tap root of koa haole growing through crevices of bedrock.** ***Right:*** **Wayside koa haole plant heavily laden with green pods; leaves starting to shed in early summer.**



can be separated from the empty pods by shaking them through a ¼-inch mesh screen.

Koa haole, like many other legumes, has a certain proportion of so-called "hard seed." Such seed has a coating which is impervious to moisture so that it will remain in the ground or in a germinator for a variable period up to several years without germinating. Mature koa haole seed may contain as much as 95 percent hard seed; the planting of such seed generally results in a poor and irregular stand. This impervious seed coating can, however, be readily broken by the hot-water, chemical, or mechanical method.

In the hot-water treatment, the seed is kept in water sufficiently hot to render the seed coat pervious, without affecting the embryo. Akamine (*1*) recommends that after heating water to 175° F. and turning off the heat, seed be added in the ratio of 1 pound of seed to 3⅓ quarts of water, and kept in the lukewarm water for 2 or 3 hours. Addition of the seed quickly reduces the water temperature below the point at which the embryo would be killed. Some ranchers use large vats, treating several bags of seed at a time and leaving the seed in the water for several hours. Since the drop in temperature is dependent on the size of container and the amount of seed being treated, the grower must work out the technique best suited to his facilities. If the operation is properly performed, the seed will swell considerably but the embryo will remain unaffected. The objections to this method are the time required to perfect the technique with the equipment at hand, and the necessity of subsequently drying the seed if it is to be planted with a drill or if it is to be held for any length of time before planting. Hot-water-treated seed deteriorates more rapidly on storage than seed treated by other methods. Some ranchers scatter the swollen seed. If conditions are favorable a good stand will result; otherwise such seed will deteriorate rapidly.

Hydrochloric acid and sulfuric acid are the most common of the various chemicals used to corrode the hard coats of seeds. The concentration of the acid and the length of treatment must be worked out for each species. The best procedure for koa haole is treatment with concentrated crude grade (78 percent or 60° Baumé) sulfuric acid for 13 minutes. The seed is placed in a screen basket made of copper, brass, or monel metal or other non-corrosive material and dipped in the acid for the required time; it is then removed and the excess acid allowed to drain off for about a minute. The basket and seed are then immersed in a large volume of water to weaken the acid quickly and dissipate the heat which develops when water mixes with sulfuric acid. The treated seed is then washed thoroughly with fast-running water. When all the acid has been washed off, the seed is dried and is ready for planting. This method has an advantage over the hot-water treatment in that the seed does not imbibe water and is thus easily dried. Objections are the difficulties and some danger of handling the concentrated acid. This method is not widely used locally.

Mechanical scarification is by far the most practical method. Scarifying machines can be purchased at low cost or can be made by the planter. Most such machines consist of a cylinder with its inner surface covered with some abrasive material. This surface scratches the seed surface sufficiently to permit moisture to enter. Baffle plates work the seed from the inlet to the outlet end as the cylinder is rotated. All else that is required is the means of mounting the cylinder and of revolving the cylinder. Directions for the construction of home-made machines or names of manufacturers will be furnished on request. The advantages of mechanical scarification are the lack of troublesome details inherent in the hot-water and acid treatments, the vastly larger volume of seed that can be treated in a given length of time, the elimination of the necessity of subsequent drying of the treated seed, and the longer storage period without deterioration. Several scarifiers are in operation in Hawaii.

Another scarification method, commonly used by ranchers, to get a stand of koa haole, is that of feeding the seed mixed with molasses to the animals on the range. The method is based on the often-noticed development of koa haole seedlings in the droppings of animals grazing in koa haole pastures. Payments have been made for a number of years by the Agricultural Adjustment Administration (now the Production and Marketing Administration) for the seeding of koa haole in pastures. To determine the proportion of seed which would subsequently germinate, koa haole seeds were mixed with a feed concentrate and fed to steers. The feces recovered were placed on a screen and washed to recover the seeds that escaped digestion. Fifty-eight percent of the seeds were recovered as whole seeds. These seeds were subjected without scarification to a germination test; during a 2-week period 87 percent germination was recorded. On the basis of the original amount ingested by the steers, the germination percentage was 50.46. Apparently the various digestive acids in the steers' intestine only partially digested and thus scarified the coats of the eliminated seeds without injuring the embryos. On the basis of the results, payments were allowed for koa haole seed when fed to pastured animals.

SOIL PREPARATION AND FIELD LAYOUT

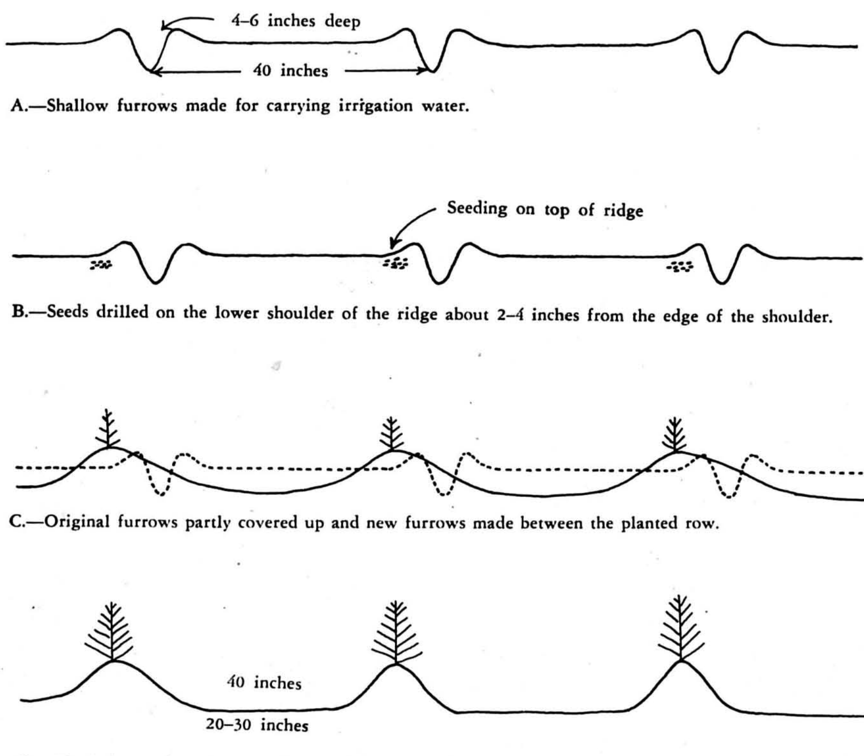
While koa haole will ultimately establish itself in an adapted area in spite of compacted soil, rocks, and weeds, careful attention to soil preparation and field layout for this slow-starting but long-lived forage crop will pay big dividends when this plant is to be grown as a soilage crop. At least two deep plowings and the necessary discings should be made to provide an open-textured soil layer for good root development. Sufficient time should elapse between plowings and the final discing to permit the germination and destruction of a major part of the dormant weed seeds. Like most perennial legumes, koa haole grows very slowly

Figure 3. ***Left:*** **When koa haole is used as a soilage crop, most of the growth is confined to a single central stem. Note the numerous dead secondary stems on the crowns of the 15-inch-high stumps.** ***Right:*** **Extreme variability in the size of plants in a thickly seeded row.**

at first and heavy weed infestation seriously impedes its early growth. Weed growth can be greatly reduced in the initial stages by at least a partial destruction of the surface weed seeds before planting the koa haole.

Since harvesting must be mechanized, as will be shown in a later section, it is essential that rows be as long as possible with a minimum of "hapa" or half rows. An intricate network of head ditches and short rows makes the use of mechanical harvesters and cultivators very difficult and even impractical. Because the same field will be cut over, say, three times a year for perhaps 10 years or more, a careful survey followed by any necessary ground leveling and relocation of head ditches to permit longer rows would be amply justified.

If the crop is to be grown with overhead irrigation or is dependent on natural rainfall, the rows may run on the contour or at whatever slope is best suited to mechanical harvesting. Once the crop is established there is little danger of erosion. Under these conditions, a field containing a considerable number of loose rocks may be used, provided sufficient time is taken to remove those which would damage the harvesting machines.



A.—Shallow furrows made for carrying irrigation water.

B.—Seeds drilled on the lower shoulder of the ridge about 2–4 inches from the edge of the shoulder.

C.—Original furrows partly covered up and new furrows made between the planted row.

D.—Final shape of newly made furrow; it is very wide and shallow.

Figure 4. Progressive shaping of ridges and furrows.

PLANTING FOR SOILAGE PURPOSES

Fifteen to 30 pounds of seeds are required to plant an acre for forage production. The seeds should be drilled about 2 inches deep in rows 2½ to 4 feet apart. The plants in the final stand should be 1 to 3 inches apart. With wide spacing the stems tend to become large and unpalatable to animals. Any standard drill may be used, although special plates should be cut to permit the dropping of two to three seeds per hole. A two-row planting is advantageous and permits the use of two-row cultivators. The depth of seeding can be accurately controlled by proper adjustment of the shoe attachment on the planter. The rows should be spaced to accommodate the particular type of machinery to be used for cultivation and for harvesting for soilage purpose.

For mechanical harvesting and cultivation a machine drill is desirable. This places the seed in a narrow band not more than an inch wide, which will permit the cultivators to come within an inch of the planted row and thereby obviate the necessity of hand weeding. If the seed is hand-planted, the width of drilling will vary from 2 to 10 inches; any weeds that grow inside the planted row must be removed by costly hand methods.

If the field is to be watered by a furrow irrigation system, seeding on the shoulders of small furrows is recommended. The furrows are widened with each successive cultivation so that at the final cultivation, about 3 months after seeding, the planted rows will be on top and centered on the ridge. The irrigation furrows should be relatively shallow and flat-bottomed. Such furrows will aid materially in keeping the tractor in line at the time of harvest. Figure 4 shows the progressive changes involved in the shaping of ridges and furrows.

CULTIVATION

During the first 3 months of growth, frequent cultivations are required to keep weeds in check; otherwise, the young koa haole plants will be all but smothered out. Although the crop will eventually fight its way through a dense weed growth, the weed competition will show itself for some time in reduced yields and slow recovery after cutting. There is little excuse for letting the weeds get out of hand as they can be effectively controlled if cultivated at the right time. If the fields are laid out properly, 8 to 10 acres a day can be cultivated by a two-row tractor-mounted cultivator. Disc cultivators are best suited for this purpose, particularly if the field is rough or trashy. Three to five cultivations during the 3-month period of establishment are usually sufficient to control the weeds effectively.

If the field has been kept essentially weed-free until the first harvest, the deep-rooted koa haole can hold its own against most weeds and grasses thereafter. In pastures it grows indefinitely in association with Guinea grass, paspalum, kikuyu, or Bermuda, provided grazing is properly controlled. The necessity of keeping a field of koa haole grown as a soilage crop free from grasses and weeds is an open question. The crop tends to shade out most annuals. Under non-irrigated conditions its greater drought resistance gives it dominance over other species. One grower on Maui has not cultivated a crop grown under such conditions for 3 years and the field is not excessively weedy. The smaller grasses, like paspalum, kikuyu, Bermuda, or the kukaipuas (*Digitaria* spp.), probably would not materially reduce the yield over that of clean culture. Tall bunch grasses like Napier grass, Guinea grass, or sour grass would probably depress the yields of koa haole and ultimately displace it under cut forage conditions. It seems good practice to keep out these tall grasses by an occasional cultivation or spot hoeing. In any event, the control of weeds in a field of koa haole after it is once established is small cause for worry. This feature is of great importance when one considers the difficulties involved in growing alfalfa.

IRRIGATION

A unique and highly significant characteristic of koa haole is its ability to make satisfactory growth for soilage purposes with moisture requirements considerably below those of most other crops. This is without doubt due to the deep rooting system of the plant and its adaptability to relatively dry climates. Stands of koa haole, once established, are unaffected by long periods of drought. Even though the leaves drop and the young stems die, with the return of rainfall the plant recovers with remarkable vigor and rapidity. At the University Farm or at Poamoho Experimental Farm, Napier grass and alfalfa require irrigation every 10 days to 2 weeks for satisfactory growth during the dry summer months. Koa haole has grown satisfactorily with only three irrigations during an entire crop of 4½ months at Poamoho Farm. In an irrigation experiment, in only two crops during a 27-month period did subsequent irrigation substantially increase yields over the plots receiving only one irrigation immediately after cutting. During this period, the mean annual rainfall was 28 inches, with a range of 0.74 to 4.78 inches per month for the different crops. It was estimated that 40 inches of rainfall per year, if evenly distributed, would be adequate for koa haole at that elevation. In view of the annual as well as seasonal fluctuations common to rainfall in Hawaii, it should be entirely feasible to grow koa haole without irrigation in an area with a normal annual rainfall of 50 to 60 inches. Non-irrigated production would make possible the use of lands for which irrigation water is not available; it would also permit the use of lands which because of slope or irregular topography would not be adapted to furrow irrigation. The long rows and absence of irrigation flumes and furrows would be of marked advantage in mechanized cultivation and harvesting. Where overhead irrigation with portable pipes is feasible, an occasional irrigation during a dry period would permit uniform production. In any event, the irrigation cost of producing a crop of koa haole would be markedly less than that for Napier grass or alfalfa or other moisture-sensitive crops.

Figure 5. ***Left:*** **For soilage at Mahelona Dairy, koa haole is topped 4 feet above the ground.** ***Right:*** **General view of koa haole stand in experiment on height of cutting at Poamoho Experimental Farm.**

PERIOD OF ESTABLISHMENT, HEIGHT OF CUTTING, AND FREQUENCY OF HARVESTING

The only local experience with koa haole as a soilage crop had been with well-established wild stands of older plants with trunks of 1 to 2 or 3 inches in diameter. It seemed possible that the premature cutting of the young seedlings would materially retard subsequent forage yields. In one series of trials, the seedlings were harvested 6, 9, and 12 months after planting. Results showed little difference in yielding ability over a 2-year period and the shorter preliminary growth period seems preferable.

It had been common practice to pluck branches or top the koa haole plants, leaving a trunk 3 to 4 feet in height. This procedure, while permissible for hand cutting, would make mechanical harvesting very difficult. Yield data were secured over a 2-year period from plots cut at levels varying from 3 to 30 inches. Fortunately in terms of yield and quality of forage, the lowest level of cutting appeared the best. It was also found that the low-cut plants kept the rank growing weeds in the row under control more effectively.

It was known that koa haole would recover satisfactorily when periodically topped, but the general practice had been to cut the growth at long intervals, with a resultantly high proportion of useless woody stem. As a satisfactory planted soilage crop, it would be necessary to reduce the cutting interval and increase the percentage of palatable leafy forage. Experiments showed that when the cutting frequency was varied from 2 to 4 months, sustained production on the basis of both yield and quality was best at about a 3-month growing period or four crops a year. Since the rate of growth varies with the season, the cutting frequency should be adjusted accordingly. During the summer months, koa haole grows more rapidly and could be harvested at, say, 2½-month intervals; during the winter 3½ to 4 months might be required.

HARVESTING

It was first thought that harvesting of the hard-stemmed koa haole might prevent its economical production as a forage crop. Hand-cutting with a sickle or cane knife is much more difficult than with Napier grass. An experienced man can hand-cut 6 tons of Napier grass a day but would do well to cut 1 ton of koa haole forage

Figure 6. ***Left:*** **Heading koa haole at the University Farm with a corn binder.** ***Right:*** **Close-up of the corn binder.**

per day. It was found that a standard power-driven corn binder was exceptionally well adapted to harvesting the crop. The wear on the machine has not been excessive; such machines have been in almost daily use for 4 years without any major repairs. One grower protects the machine from protruding rocks and deep irrigation ditches by a piece of heavy sheet iron fastened to the bottom of the frame like a skid or sled.

With repeated cutting of the top portion the plant gradually develops a sizable stump and it was supposed that each subsequent cutting would have to be made slightly higher than the previous one. Such has not been the case, however. Four-year-old plantings are still cut at the same level, about 4 inches above the ground. Aside from an occasional broken sickle section or stationary side knife the corn binder suffers no obvious damage. The grower with the sled attachment to his binder cuts the koa haole essentially at ground level; the sled apparently somewhat mutilates the stumps but in 4 years has not damaged the rugged crop. The bundles of koa haole resulting from harvesting with the corn binder are easily handled—one bundle of koa haole about 4 feet high weighs about 30 pounds.

Recently an ensilage harvester was tried on koa haole with complete success. This machine not only cuts the koa haole but also chops the harvested forage into 1-inch pieces which are then delivered into a trailer which is hitched to the harvester. The machine eliminates hand loading of the cut forage completely and is, therefore, 100 percent mechanized. It is estimated that this machine can cut, chop, and deliver a ton of koa haole to the barn at an approximate cost of $1.00. The only difficulty in the way of complete mechanization is the damage to rubber-tired equipment caused by the sharp woody stumps. If care is used in keeping the rubber tires of tractor and binder astride the rows, the use of such equipment is feasible; better still would be the use of a track-laying type of tractor.

METHODS OF UTILIZATION OF THE CUT FORAGE

The cut forage of koa haole is ordinarily fed in the green condition in much the same manner as alfalfa. The forage must either be fed soon after it is cut or placed under cover where it will not dry out, since the leaflets drop off as soon as they begin to dry. For efficient utilization, the forage must be chopped; otherwise the animals eat only the leaves. In the chopped forage the animals refuse only the pieces of large mature stem.

Preliminary investigations (7) on the ensiling of chopped koa haole in 40-gallon steel barrels indicate that no special difficulties are involved. The final ensiled product was comparable in appearance, odor, and acidity to other ensiled legumes. When koa haole was ensiled with Napier grass or strip cane in the proportions of 1 to 1 or 1 to 2, the product was considerably more nutritious and palatable than Napier grass ensiled alone. The silo would be particularly advantageous in making effective use of harvesting machinery and of the seasonal growth of the crop under non-irrigated conditions. Thus far, however, the silo has not been generally accepted, primarily because green feed of some sort is present the year round. Dairymen feel that the added equipment and labor required, together with the losses resulting from the ensiling process, do not make up for what appear to be the somewhat intangible advantages.

During the war the critical need for a substitute for alfalfa in poultry rations, and a higher protein forage for dairy animals, prompted investigations of the collection of koa haole forage from wild plantings and of drying the forage. One ton of freshly harvested and chopped koa haole forage was run through the large rotary driers used by the local pineapple companies for the preparation of pineapple bran. No difficulty was encountered in the drying process and the resulting product, when passed through a hammer mill, looked like prime alfalfa meal. With the resumption of shipping from the coast this work was discontinued but the excellent results obtained from the use of small amounts of koa haole leaf meal in poultry ration may justify the production of koa haole leaf meal on a commercial scale.

SUMMARY OF RECOMMENDATIONS ON ESTABLISHMENT AND MANAGEMENT

Adaptability.—Koa haole is best adapted to the comparatively low elevations on the leeward sides of the islands. It should not be planted at elevations above about 700 feet or where the annual rainfall exceeds about 75 inches.

Land preparation.—The land should be well prepared, and most of the troublesome weed seeds destroyed before planting.

Field layout.—Since the crop can be cultivated and harvested mechanically the rows should be as long as possible, with a minimum of "hapa" rows. The rows should be spaced about 3½ feet apart.

Plantings.—Plant 20 to 25 pounds of scarified seed per acre. Mechanical scarification is the most practical method. The final stand should have three to six plants per running foot. Use a two-row planter, if possible, and drill the seeds 1 to 2 inches deep.

Cultivation.—Weeds must be kept under control during the first 3 or 4 months, or until the seedlings begin to close in. Use a two-row tractor-mounted cultivator equipped with disc tools. After the first crop is harvested only occasional cultivations are needed.

Irrigation.—Koa haole requires much less irrigation than most other legumes or grasses; except under very dry, hot conditions, one irrigation per crop is sufficient. The crop may be grown without irrigation in areas receiving 40 to 60 inches of rainfall annually.

Frequency of cutting.—The crops should be harvested when they are 3 to 5 feet tall; under most conditions this results in three to four crops per year.

Harvesting.—Harvest with a corn binder or an ensilage harvester. Standard machines are well adapted for harvesting this crop. Hand cutting is impractical.

KOA HAOLE PASTURES

Koa haole is used quite extensively for pasture purposes. Although no actual data are available, many thousands of acres of pastures contain appreciable amounts of koa haole. Many of them result from natural seeding, but in recent years koa haole has been extensively seeded on the relatively dry range lands. In most places the seed has been broadcast without any land preparation. In some of the better parts of these wild koa haole pastures the plants are occasionally topped back to 3 to 4 feet above ground level to encourage new growth at levels accessible to livestock. As all the topping is done by hand, the cost is rather high. The topography is generally too rough to permit the use of portable machine saws.

For prepared fields and planted pastures it is desirable to interplant koa haole with some sort of a grass cover. Interplanting will keep the weed growth to a minimum, add materially to the carrying capacity, and provide a more varied and better balanced forage. The interplanted grasses will probably receive sufficient nutrients from the associated legume so that little or no fertilization will be required. Under a paired-row layout, two rows of koa haole are planted about 3 feet apart with about a 6-foot space between two such pairs. The grasses are planted only between the wide spacings between paired rows of koa haole. The grass should be interplanted 2 to 3 months after the seeding of koa haole to permit free cultivation of inter-row space during the early stages of growth and also to give the slower-growing legume sufficient time to become well established. Guinea, Bermuda, and Dallis grass work well for such interplantings. The combination of koa haole and Guinea grass is widely used in the relatively dry zones and is regarded as a first-class fattening mixture.

As a pasture legume koa haole requires careful management. Since it is exceptionally palatable, overgrazing will seriously impair the rapidity of recovery and subsequent productivity. On the other hand, undergrazing will result in excessive growth so that within a short time the plants will grow so tall that they will be out of reach of the cattle. Overgrown koa haole is of little use to cattle as little new

Figure 7. *Left:* Koa haole–Guinea grass pasture in Kona, Hawaii, ready for grazing. *Right:* New growth developing on tall koa haole plants after grazing at Mahelona Dairy.

growth takes place at levels accessible to cattle. The woody stems are inflexible so that the foliage on the top seldom bends down by its weight. When koa haole becomes too tall for grazing there is no recourse except to top it back or wait for the young seedlings to spring up under it. For the most effective grazing, the old stems should not exceed 3 to 4 feet in height. If koa haole pasture is planted in rows on relatively smooth land periodic topping can be done with a tractor-mounted mower set at the desired height.

At present dairymen are quite interested in planting koa haole for grazing purposes. On Kauai one dairyman who used his fields of koa haole as a source of cut forage for many years is now grazing them with satisfactory results. Other dairymen plan to follow this procedure. This system has definite advantages as a means of saving labor. Although no actual grazing data are available, it seems probable that considerably greater yields per acre and better utilization of the forage would result from harvesting and feeding the cut forage. The dairyman should thus balance his available acreage against his demands for forage. Alternate grazing and mechanical harvesting are also possible.

EXPERIMENTS ON CULTURAL PRACTICES

The following section gives the results of several experiments, conducted over a 7-year period. We were dealing with an essentially unknown crop, and some experiments were abandoned as soon as the unsuccessful or impractical procedures became evident. Since the response or reaction of the crop to various treatments could not be forecast, some of the experiments did not give all the desired information. It is believed, however, that the data secured were adequate to form the basis for sound recommendations on the methods of establishment, culture, harvesting, and expected yields.

VEGETATIVE PROPAGATION

Koa haole planted from seed is among the slowest growing of leguminous crops, requiring a minimum initial growth period of about 6 months. Various individuals have reported that koa haole grows readily from stump plantings (*i.e.,* the crown and root system of sizable plants) and that even stem cuttings, when stuck into the ground, will generally grow. Experiments were conducted to determine the feasibility of using vegetative materials for propagation with the hope of cutting down the initial growth period. Subsequent experiments on the relative yields of stands obtained from vegetative materials compared with direct seeding have shown the marked superiority of the latter, and only a brief résumé on vegetative propagation will be presented.

Two types of vegetative materials were used; stem cuttings about 30 inches long but varying from ½ to 3 inches in diameter, and stumps of various sizes ranging from ¼ to 2 inches in diameter with a variable length of attached stems from 3 to 30 inches long. In the preparation of stumps, whole plants were dug out and the tap roots were cut back sufficiently to leave about 8 inches attached to the plants. The stems were then topped back to 3, 15, and 30 inches. To accommodate the partially trimmed tap root, holes had to be dug and the stumps planted in these holes. The stem cuttings were planted in three positions—vertical, horizontal, and at a 60° angle from horizontal. Seed plantings were used as check plots. The field was irrigated throughout the experiment. Data were taken on percentage of germination, rapidity of germination, and growth and forage yields.

Results showed that regardless of the size of the stumps or the length of the attached stems, the percentage take was almost perfect for every type of stump planting. The best percentage take recorded from stem cuttings was obtained from the largest cuttings planted vertically and at a 60° angle, both being greatly superior to the horizontal position. The highest take of the stem cuttings was only 26.7 percent, and the percentage take rose with the increase in the diameter of the cuttings.

The rapidity of the growth and forage yields of the first crop of the various types of planting materials ranked in the following descending order: (1) stump, (2) plants grown from seeds, and (3) stem cuttings. The rapidity of growth and forage yields from stump plantings decreased progressively with an increase in the diameter of the stumps and in the length of the attached stems. In the smaller stumps the tap roots were enlarged and had small ruptures on the epidermis from which new roots sprouted readily. It appears that the small stumps made the best growth because of their ability to produce new roots rapidly and profusely. Root development on the larger stumps was meager.

In view of the excellent stand obtained from the smaller stump plantings and the rapid growth of the first crop, an experiment was installed at Poamoho Farm to compare the relative yields of stump plantings and direct seeding. The layout was on the randomized block principle with 12 replications. The data were analyzed by "Student's" method. There was no question as to the greater rapidity of the growth of the initial crop of the stump plantings; the plant crop was harvested 131 days after planting as compared to 259 days for the direct seed plantings. Subsequent ratoon crops, however, were harvested at about the same growth intervals for the two types of planting materials as there was no difference in the rapidity of recovery. The experiment was terminated after 3 years of study. Over the 3-year period direct seeding showed statistically higher yield than the transplants, the mean yields of green forage per acre per year being 22.13 tons and 17.45 tons, respectively. The cost of preparation and planting any sizable acreage of stumps would also be prohibitive unless the entire process were mechanized.

FREQUENCY OF CUTTING OF KOA HAOLE AND DESMANTHUS

A field experiment, laid out at the Pensacola Branch Station, included three frequencies of cutting treatments and two species of legumes in all possible combinations of 3 $\times$ 2 treatment types. The two species of legumes were koa haole and desmanthus, the latter being closely related to koa haole but bushier in growth habit and with finer leaves and smaller narrow pods. The layout was on the com-

Figure 8. Harvesting experimental plots of koa haole with a motor scythe.

pletely randomized block principle with four blocks of six plots each. Each plot consisted of four rows, 3 feet apart and 26 feet long. Acid scarified koa haole seeds were hand-drilled in rows at the rate of 15 pounds to the acre and covered with 1 inch of soil. Desmanthus seeds, which had been scarified in concentrated sulfuric acid for 8 minutes, were drilled in rows at the rate of 5 pounds per acre and covered with a half inch of soil. The field was planted in July 1939, and the plant crop was harvested uniformly after approximately 6 months of growth. Owing to the lack of uniformity in growth in some plots, the first ratoon crop was likewise harvested uniformly and from this date the frequency of cutting treatments began. The experiment was concluded in April 1943, after 3 years of study. The cutting treatments were harvested every 61, 91, and 122 days, which is equivalent to six, four, and three harvests per year. These cutting frequencies are henceforth referred to as 6×, 4×, and 3× cuttings. The weeds were kept out by cultivation with a garden tractor about once every 2 months, and the field was irrigated with overhead sprinklers when necessary, about twice a month.

All plots were cut with a motor scythe, 2 to 3 inches above ground level. Border rows on each side of the plot, as well as 3 feet on each end of the row, were removed before plot weights were taken. Green weights of the two interior rows were recorded in the field immediately after the plots were cut and samples were taken to be used later for the determination of dry matter, chemical composition, and percentage of leaves. In determining the leafy portion, the following somewhat arbitrary method was used: holding the basal part of the stem with one hand and snugly clasping the stem with the other hand where the first basal leaf was located, the stems were stripped toward the apex with a quick motion. The stripped portion consisted of the leaves, petioles, and the more succulent parts of the stems.

Forage yields: A summary of yields of whole green forage and oven-dry forage for the entire 3-year period is presented in tables 1 and 2.

Analysis of variance of whole green forage yields showed a significant difference at the 1 percent point, in cutting frequency and species treatments as well as in the interaction: year × species. There was very little difference in yield between the 4× and 6× cutting treatments but both were significantly higher than the 3× cutting treatment. Koa haole had a significantly higher yield than desmanthus. There was no significant difference in yield between years in the koa haole, but the first-year yield of desmanthus was significantly higher than those of the second and third years, with no difference between the latter 2 years. There was no difference in yield between the two species for the first year but in both the second and third years koa haole outyielded desmanthus. There was, however, no significant difference in yield between years when the two species were considered together.

Throughout the 3 years of the experiment there was a distinct fluctuation in yield from one part of the year to another, the yields decreasing sharply during the winter months and rising again with the approach of summer. On the average the peak summer production was fully 50 percent higher than the lowest ebb of winter production. In certain plots as high as a 400 percent increase was noted in the summer over the winter production. This fluctuation in yields due to season was most pronounced in the 6× cutting treatment.

Since both koa haole and desmanthus were separated into leafy portions and stems at the time of harvest, yields of the green leafy portions were also calculated.

TABLE 1. Mean yield of fresh whole forage of koa haole and desmanthus in tons per acre per annum harvested at varying intervals over a 3-year period.

YEAR	SPECIES						YEAR × SPECIES			YEAR × CUTTING FREQUENCY			YEARLY MEAN
	Koa haole			Desmanthus									
	Cutting frequency			Cutting frequency			Koa haole		Desmanthus	3×	4×	6×	
	3×	4×	6×	3×	4×	6×							
1940......	22.78	25.95	22.96	21.37	26.09	28.00	23.90		25.15	22.07	26.02	25.48	24.52
1941......	23.73	25.50	27.77	17.56	21.55	24.28	25.67	±3.23*	21.13	20.65	23.53	26.02	23.40
1942......	23.64	26.64	24.37	16.92	24.32	21.05	24.88		20.76	20.28	25.48	22.71	22.82
Mean.....	23.38	26.03	25.03	18.62	23.99	24.44	24.82		22.35	21.00	25.01	24.74	
Treatment factors	Cutting frequency × species						±1.98* Species			±2.43* Cutting frequency			

* Significant at 1 percent point.

TABLE 2. Mean yield of oven-dry forage of koa haole and desmanthus in tons per acre per annum harvested at varying intervals over a 3-year period.

YEAR	SPECIES: Koa haole, Cutting frequency 3×	4×	6×	SPECIES: Desmanthus, Cutting frequency 3×	4×	6×	YEAR × SPECIES: Koa haole		Desmanthus	YEAR × CUTTING FREQUENCY: 3×	4×	6×	YEARLY MEAN
1940......	8.50	9.07	6.97	9.72	10.93	9.97	8.18		10.21	9.11	10.00	8.47	9.19±0.66*
1941......	9.20	9.58	7.58	7.22	7.69	7.43	8.78	±1.14*	7.45	8.21	8.64	7.50	8.12±0.66
1942......	7.42	8.87	6.84	6.40	8.29	6.54	7.71		7.08	6.91	8.58	6.69	7.39±0.66
Mean.....	8.37	9.17	7.13	7.78	8.97	7.98	8.22		8.24	8.08	9.07	7.55	
Treatment factors	Cutting frequency × species						Species			±1.17† Cutting frequency			

* Significant at 1 percent point.
† Significant at 5 percent point.

The general trends were similar to the yields of whole green forage but as was expected the differences between treatments were much more pronounced. On the basis of yield of leafy portions, koa haole outyielded desmanthus by 34 percent compared to 11 percent on the whole forage basis. There were significant differences between frequency of cutting treatments, the yields of the leafy portion decreasing progressively with decrease in frequency of cutting. There was no difference in the yield of koa haole over the 3-year period, but the first-year yield of desmanthus was significantly higher than that of the last 2 years. Significant interactions were noted between year × cutting frequency, year × species, and year × cutting frequency × species.

In the yield of oven-dry matter the two species did not differ. There was a definite reaction to year, the yields decreasing progressively from the first to the third year. At the 5 percent point, the 4× cutting treatment had a significantly higher yield than the other two treatments. There was no difference in yield between years of the koa haole, but the first-year production of desmanthus was higher than that of the last 2 years. The first-year yield of desmanthus topped that of koa haole for any one year.

Chemical composition: Data on chemical composition are presented in table 3. Koa haole is decidedly higher than desmanthus in percentage of protein at all cutting frequencies, having 41.86 percent higher protein content on the oven-dry and 27.83 percent on the fresh-weight basis. A sharp increase in protein content of the whole forage on the oven-dry basis was noted in koa haole and desmanthus as the cutting intervals were shortened. The 6× cutting of koa haole showed an increase of 26.34 percent and 52.12 percent in protein content over the 4× and 3× cuttings. Desmanthus likewise showed similar trends. On the fresh basis, however, there was relatively little difference in protein content between cutting frequencies and species. In koa haole the 6× cutting exceeded the 3× cutting by only 18.45 percent.

The percentage of protein in the leafy portion varied relatively little between cutting treatments and between species. In koa haole the 6× cutting treatment had 24.62 percent higher protein content than the 3× cutting on the oven-dry basis but in desmanthus the 6× cutting treatment was only 7.5 percent higher than that of the 3× cutting treatment. The protein content in koa haole leaves exceeded that of desmanthus by 19.42 percent. The percentage of protein in the leaves was roughly three times that of the stems proper.

The percentage of protein in the stems increased slightly but progressively with the shortening of the cutting interval. Koa haole stems had a definitely higher protein content than desmanthus stems for all cutting frequencies. On the fresh-weight basis the stems of these two legumes had a higher protein content than a top-grade whole Sudan grass forage.

The total production of protein in the different treatments is presented in table 4. The analysis of the data shows that koa haole is markedly superior to desmanthus in the the yield of protein, the respective yields being 2,887 and 2,175 pounds per acre per year. Both the 4× and 6× cutting treatments had significantly higher yield than the 3× cutting treatment. The yield of protein decreased progressively as the plants grew older, the third-year production being significantly lower than that of the first year. In desmanthus, protein yield increased progressively with the decrease in cutting interval, but for koa haole the 4× and 6× cutting treatments were about equal and markedly superior to the 3× cutting treatment.

TABLE 3. Percentage oven-dry matter and protein in different parts of the plant of koa haole and desmanthus harvested at varying cutting frequency.

PART OF PLANT	KOA HAOLE									DESMANTHUS								
	3X			4X			6X			3X			4X			6X		
	Dry matter	Protein		Dry matter	Protein		Dry matter	Protein		Dry matter	Protein		Dry matter	Protein		Dry matter	Protein	
		Dry basis	Fresh basis		Dry basis	Fresh basis		Dry basis	Fresh basis		Dry basis	Fresh basis		Dry basis	Fresh basis		Dry basis	Fresh basis
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Leaves	31.89	24.13	7.70	30.82	26.05	8.03	24.71	30.07	7.43	32.03	21.60	6.92	28.63	22.39	6.41	28.20	23.22	6.55
Stem	41.30	8.06	8:33	38.03	9.14	3.48	31.21	10.04	3.13	44.94	6.40	2.88	39.13	6.74	2.64	35.34	8.18	2.89
Whole forage	37.15	14.60	5.42	34.47	17.58	6.06	28.91	22.21	6.42	41.75	10.55	4.40	36.98	12.27	4.54	32.68	15.52	5.07

TABLE 4. Mean yield of protein in pounds per acre per annum in koa haole and desmanthus harvested at varying intervals over a 3-year period.

YEAR	SPECIES						YEAR × SPECIES		YEAR × CUTTING FREQUENCY			YEARLY MEAN
	Koa haole			Desmanthus								
	Cutting frequency			Cutting frequency			Koa haole	Desmanthus	3×	4×	6×	
	3×	4×	6×	3×	4×	6×						
1940	2469	3240	3076	1739	2744	2944	2928	2476	2104	2992	3010	2702±261.77*
1941	2505	2986	3377	1612	1931	2576	2956	2040	2058	2458	2976	2497±261.77
1942	2352	2996	2984	1469	2071	2491	2777	2010	1910	2534	2738	2394±261.77
Mean	2442	3074	3146	1607	2249	2670	2887	2175	2024	2661	2908	
Treatment factors	Cutting frequency × species						±312.34* Species		±382.71* Cutting frequency			

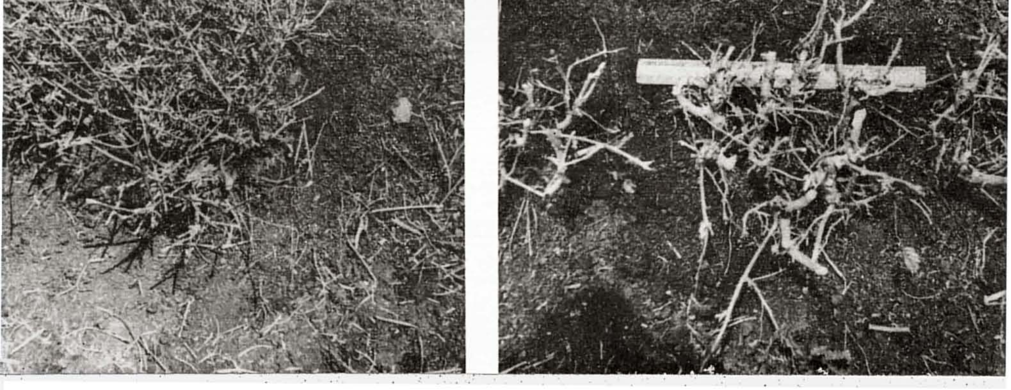
* Significant at 1 percent point.

Figure 9. Koa haole of the 3× cutting ready for harvest.

Growth behavior: Both koa haole and desmanthus were fairly well established and gave creditable yield when the plant crop was harvested 6 months after planting. The first ratoon crop which was harvested uniformly yielded remarkably well, koa haole producing at the rate of 38.63 tons per acre per year and desmanthus at the rate of 40.15 tons.

At the time of harvest, desmanthus had a heavy crop of dry pods but koa haole had only a few immature pods. The recovery of desmanthus was invariably faster

Figure 10. Crown development after periodic harvesting over a 3-year period. *Left,* desmanthus; *right,* koa haole.



than that of koa haole. In the desmanthus plots the plants in the 6× cutting frequency were in the early bloom stage, those in the 4× cutting frequency in the early podding stage, and in the 3× cutting frequency in the mature pod stage. In the koa haole plots growth in the 6× cutting frequency was entirely vegetative, that in the 4× cutting frequency in the bud or early bloom stage, and in the 3× cutting frequency the plants were in the early podding stage.

The difference in growth habits of desmanthus and koa haole was quite distinctive. Desmanthus developed a crown similar in many respects to that of alfalfa. The size of the crown gradually increased with each successive crop and at the time of termination of the experiment many of them were over 6 inches across. Like the alfalfa, a well-developed vigorous crown produces as many as 50 stems which are slender but erect. The stems are seldom branched, are pithy in the center, brittle, and fairly soft. Probably because of the dense, erect tillering growth habit of the plants, there was considerable etiolation in the lower part of the stem, which made the plants appear "leggy." The small size and the brittleness of the stems posed no problem in the harvesting of desmanthus even by hand methods.

There was no semblance of crown development in koa haole, and only a few stumps were over 2 inches in diameter at the end of 3¾ years of growth. Each plant produced from 6 to 10 stems of which 1 to 3 of the main stems with their laterals produced the bulk of the forage. The growth was fairly open and there was no indication of etiolation even in the basal leaves of the 3× cutting frequency. The base of the stems, even in the youngest plants, was tough and woody and difficult to cut by hand.

The percentage of leaves increased considerably as the cutting frequency was increased for both species. In koa haole the 6× cutting had 40 percent more leafy portion than the 3× cutting while in desmanthus the increase was approximately 50 percent. Koa haole was definitely more leafy than desmanthus, the mean percentage of leaves for all cutting frequencies being 22 percent higher in favor of koa haole.

Discussion and conclusions: This experiment has shown that both koa haole and desmanthus can be grown as soilage legumes in much the same way as a field of alfalfa. In desmanthus the yields of oven-dry forage of the second and third years were significantly lower than those of the first year. This drop in yield may not necessarily mean a lack of persistence, as observation of the crowns at the end of almost 4 years of growth showed no actual mortality. In the 6× cutting treatment of koa haole the yield of oven-dry matter was practically the same for all 3 years. In this treatment a total of 20 crops was harvested at the time of termination of the experiment. The consistency in yield over a span of 20 crops cut at an immature stage clearly indicates great persistence of koa haole as a soilage legume. One dairy on the island of Kauai has grown koa haole for forage production for 14 years from a single planting with no evidence of deterioration. On one large estate it has been maintained as a hedge plant with periodic topping for over 40 years.

At its best alfalfa is superior to koa haole and desmanthus in yield of green forage, but because of the greater dry matter content in the latter two legumes, the yield of oven-dry matter is equal to alfalfa. According to Morrison (*24*) the average analysis of alfalfa from 146 samples is 4.6 percent total crude protein on the fresh-weight basis. Present data show koa haole to be about 30 percent higher

Figure 11. Close-up of a trimmed koa haole hedge.

than alfalfa, and desmanthus the equal of alfalfa. Henke's (*16*) data likewise show the marked superiority of koa haole over alfalfa in percentage composition of protein with no difference between desmanthus and alfalfa. The production of protein is just about even for koa haole and alfalfa, the higher composition of koa haole being offset by the higher green forage yield of alfalfa.

In the yield of oven-dry matter the 4× cutting frequency was statistically higher at the 5 percent point than the other two treatments. In the yield of protein the 4× cutting frequency had significantly higher yield than the 3× cutting frequency and was not significantly lower than the 6× cutting frequency. Considering both of the above yield criteria, the 4× cutting frequency appears to be the best for all around production. Under actual field practice the cutting frequency should be made flexible so that during the accelerated summer growth the interval between harvests should be shortened and during the slow winter growth the interval should be increased correspondingly.

Koa haole outyielded desmanthus in protein by a third. Although there was practically no difference in the yield of oven-dry matter during the 3 years of cropping, it is possible that over a much longer period koa haole would outyield desmanthus. The statistical analysis indicated that the second- and third-year yields of desmanthus were significantly lower than those of the first year, whereas for koa haole there was no statistical difference for the 3 years although actually the drop in the third-year production appeared to be somewhat greater than the normal fluctuation in yield.

Henke (*16*) obtained about 50 percent higher forage yields from desmanthus at the University Farm than those reported in our test. Better soil fertility and tilth,

Figure 12. General view of a trimmed koa haole hedge over 40 years old.

more favorable soil moisture relationship, and the materially longer cropping interval were probably responsible for the higher yield. Desmanthus grown at the University Farm was generally harvested when the plants were well matured and over 6 feet tall. The stems were several times larger in diameter than those harvested in our longest cutting interval. Henke states that at first the yields were satisfactory, but after 3 years of growth the yields dropped because of excessive weed growth.

Koa haole is much more resistant to drought and has a wider range in altitude than desmanthus. Koa haole also seems to be less affected by weed competition. As a soilage legume we consider koa haole superior to desmanthus. In view of this fact desmanthus was eliminated in subsequent studies on the various phases of management of koa haole as a soilage legume.

RESPONSE TO FERTILIZER

Koa haole appears to be well adapted to a wide range of soil types as indicated by its widespread distribution on various parts of the islands. However, at least under cultivation, great variation in plant growth has been noted within a small area. An experiment was installed to ascertain the response of koa haole to fertilization at Poamoho Farm, where the soil is moderately acid (*p*H 4.5 to 6.5) and deficient in available lime, phosphate, and potash.

This experiment was installed in July 1942 and terminated 3 years later. The field layout consisted of a split-plot design with two main-plot treatments of no nitrogen and nitrogen fertilization replicated four times, and sub-plot treatments of five fertilizers randomized within each whole plot. Nitrogen was applied as surface dressings but all other fertilizers were hoed in the bottom of the furrows at the time of planting to incorporate them as thoroughly as possible into the top inches of soil. The first nitrogen application was made 4 weeks after liming to avoid possible reaction between the two fertilizers.

Each plot consisted of six rows 3⅓ feet apart and 20 feet long. Scarified seed was drilled in rows to the depth of 1½ inches at the seeding rate of 25 pounds per acre. The seed was planted with a Farmall double-row seed planter.

The weeds were kept in check by periodic disc cultivation with the Farmall "A" tractor. The field was given surface irrigation about once every 2 weeks. The first three crops were hand harvested and the remaining four crops were harvested with the corn binder. Whether cut by hand or by the corn binder the height of cutting was kept as near ground level as possible. Border rows, as well as 2 feet on each end of the row, were removed before plot weights were taken. The plant crop was harvested 248 days after planting. Subsequent crops were harvested when they were at least 4 feet tall or in the early bloom stage.

The results of the green forage yields are given in table 5. Analysis of the data showed significant response to both the main-plot and sub-plot treatments. The main-plot treatments were significant at the 5 percent point while the sub-plot treatments were significant at the 1 percent point. In the sub-plot treatment the four

TABLE 5. Mean green forage yields of koa haole in tons per acre per year treated with varying fertilizer constituents singly and in combinations.

TREATMENT*		YIELD IN TONS PER ACRE PER YEAR	
Main-treatments	No nitrogen	19.36	
	Nitrogen	22.08†	
Sub-plot treatments	0	18.32 ± 0.97‡	
	Ca	19.39 ± 0.97	no significant difference but > 0
	P	19.86 ± 0.97	
	Ca P	23.32 ± 0.97	no significant difference but > P, Ca, and 0
	Ca P K	22.71 ± 0.97	

* Nitrogen applied in the form of ammonium sulfate (21.5 percent N) at the rate of 64.5 pounds per acre per crop; all others applied at the time of planting in a single application in the following amounts:
Lime—2,000 pounds per acre in the form of burnt limestone, 69 percent of which was hydrated lime.
Phosphate—200 pounds per acre in the form of superphosphate (23 percent P_2O_5).
Potash—200 pounds per acre in the form of potassium sulfate (49 percent K_2O).

† Significant at the 5 percent point.

‡ Difference greater than ± 0.97 significant at 1 percent point.

fertilizer treatments were all significantly higher than the control plot. There was no significant difference between Ca and P treatments or between Ca–P and Ca–P–K treatments but the two latter treatments had significantly higher yield than Ca and P treatments.

The application of lime or superphosphate alone gave significant response but the increase over the check plots was too small to have practical significance. The combination of lime and superphosphate gave considerable increase over the check plots. The Ca–P plots had a mean annual yield of 23.32 tons as compared with 18.32 tons for the check plots, an increase of 5 tons, which is a 27.4 percent increase over the check plot. An increase of 5 tons per acre per year is probably more than enough to pay for the fertilization. Apparently the application of potash in conjunction with lime and phosphate had no effect on yield. Although the application of nitrogen gave statistically significant response, the increase in yield of 2.72 tons per acre per year was too small to offset the cost of fertilization. At any rate, judging by the color of the foliage, which was dark green even in the check plots, koa haole was getting the required amount of nitrogen from the soil and from nitrification for normal growth. Likewise the natural vegetation seldom shows any indication of lack of nitrogen.

Although we did get response from the combined application of phosphate and lime, the response was not obvious from observation; even the no-fertilizer plots appeared to be making normal growth.

In acid and moderately acid soils of the Low Humic Latosols where the availability of these constituents is low, the application of both these fertilizers increases the productivity of koa haole appreciably. This increase more than pays for the fertilization. Since both of the above fertilizers have resulted in increased yields over a 3-year period with a single application made at the time of planting, such fertilizers can be applied at intervals of 2 or 3 years. It is recommended that for new plantings at least both fertilizers be applied before seeding.

PERIOD OF ESTABLISHMENT AND HEIGHT OF CUTTING

The field layout of this experiment consisted of a split-plot design with three main-plot treatments of period of establishment replicated four times and sub-plot treatments of three heights of cutting randomized within each whole plot. In the

Figure 13. ***Left:*** **Koa haole in the fertilizer test at Poamoho Experimental Farm ready for harvesting.** ***Right:*** **General view of a field at the Pensacola Branch Station used in the experiment on frequency of cutting. Desmanthus is in the foreground; koa haole in the middle distance.**

main-plot treatment the plant crops were harvested at 6, 9, and 12 months. The period required for the growing of the plant crop is designated as the "period of establishment." The sub-plot treatments of height of cutting were initiated in each of the main-plot treatments at the time of harvesting of the plant crops at 6, 9, or 12 months. The sub-plot treatments were as follows: harvesting 0–3 inches above ground level, 15 inches above ground level, and 30 inches above ground level. The yields of the plant crop were included in working up the data on both the main and sub-plots.

Each plot consisted of four rows 3⅓ feet apart and 28 feet long. The rate of seeding, method of planting, and irrigation were the same as in the fertilizer experiment. Because of the variable growth of the plots resulting from the differential harvesting periods, it was impossible to machine-cultivate and weeds were kept in check by hand weeding. As nearly as possible the sub-plot treatments were harvested at the early bloom stage. Border rows as well as 2 feet on each end of the row were removed before plot weights were taken.

The plots were cut by hand and green weights were recorded in the field immediately after harvest. Samples were taken to be used later for the determination of moisture, chemical composition, and relative leafiness.

Results: Data on the yield of green forage are presented in table 6. The main-plot treatment of period of establishment was not statistically significant but the sub-plot treatment of height of cutting was significant at the 5 percent point. Although the difference was not large, there was a progressive decrease in yield as the height of cutting was increased and the differences between treatments were statistically significant.

Data on the yield of leafy portions were also analyzed statistically but there were no significant differences in the treatments. There was a progressive but disappointingly low increase in the percentage of leafy portions as the height of cutting was increased. The mean percentage leafy portions, excluding the data on the plant crop, were 35.51, 41.11, and 46.22 percent for the ground level, 15-inch, and 30-inch height of cuttings, respectively.

The number of crops harvested for the different sub-plot treatments of height of cutting was identical within a given main-plot treatment, although the growth period between sub-plot treatments varied considerably within and between crops. The numbers of ratoon crops harvested for the main-plot treatments were 6, 5, and 4 for the 6-, 9-, and 12-month periods of establishment, respectively. The mean growing periods for the ratoon crops of the sub-plot treatments were 150, 165, and 181 days for the 6-, 9-, and 12-month periods of establishment. We have no explanation for the continual increase in the growth period of the ratoon crops in the main-plot treatments with an increase in the period of establishment; if anything the trend should have been reversed as better established and larger plants are normally expected to recover more rapidly than younger and smaller plants. After 3 years of growth there was relatively little increase in the diameter of the original main stems except for a few plants at the ends of the field. Likewise there was no noticeable difference in the size of the stumps for the different heights of cutting.

Without question cutting efficiency decreased markedly with each increase in the height of cutting. A cutting test by hand yielded the following results:

1. Ground level cutting—405 pounds per man-hour.
2. Fifteen inches above ground level—288 pounds per man-hour.
3. Thirty inches above ground level—205 pounds per man-hour.

From practically every standpoint ground level cutting is the best for growing koa haole as a soilage crop. The lower cutting levels produce a higher yield and are the easiest to cut by hand as well as by machinery now available. With the machinery now available the maximum height of cutting is about 12 inches. Even at this level plants are bruised so much that growth renewal is mostly confined to near the ground level where the tissues have escaped injury.

The results in the period of establishment indicate that neither the persistence nor the over-all yield is affected by the length of period of establishment. This is still another indication of the inherent ruggedness of this crop. The shorter period of establishment is recommended because of the ease of harvesting of an immature crop, and the better quality forage obtainable from younger crops.

RESPONSE TO IRRIGATION

Although koa haole is highly resistant to drought, its growth is very seasonal in the wild stands. An irrigation experiment was superimposed on a 1-acre field of koa haole at Poamoho which had been planted primarily to study the various aspects of mechanization of the culture and harvesting of the crop. While it was not possible to control or measure accurately the amount of water applied, the results shed some light on the relative moisture requirements of koa haole.

Field layout and procedure: The field consisted of 60 rows extending the full length of the field; the actual row lengths varying from 150 to 192 feet. The rows were spaced 40 inches apart and laid out on the contour with a variable slope gradient of 0.4 to 0.8 percent to eliminate as many "hapa" (half) rows as possible. The field was planted in July 1943 with a standard two-row tractor-mounted drill. Scarified seed, at the rate of 25 pounds per acre, was drilled on the shoulders of the furrows. The field was uniformly furrow irrigated during the growth of the plant crop and was weeded with a standard two-row tractor-mounted cultivator equipped with disc tools. Harvesting was done with a standard single-row corn binder driven from a power take-off from the tractor.

Three levels of irrigation were used: a single irrigation per crop, intermittent irrigation, and adequate irrigation. The single irrigation per crop was applied a

TABLE 6. Mean green forage yield per plot of koa haole in tons per acre per annum harvested at varying periods of establishment and heights of cutting.

MAIN-PLOT TREATMENT PERIOD OF ESTABLISHMENT	YIELD PER ACRE PER ANNUM	SUB-PLOT TREATMENT HEIGHT OF CUTTING FROM GROUND LEVEL	YIELD PER ACRE PER ANNUM
Months	*Tons*	*Inches*	*Tons*
6	21.17	0	22.60 ± 1.22*
9	19.27	15	19.29 ± 1.22
12	19.34	30	17.90 ± 1.22

* Difference necessary between treatment means for significance at the 5 percent point.

week or two after the harvesting of the previous crop. The intermittent irrigation plots received water whenever a sharp decline was noted in the growth curve, as determined by weekly measurements of stem elongation. The adequate irrigation plots received water once a week unless the rainfall during the previous week exceeded 1 inch. Each plot consisted of five full-length rows, and had an average size of 0.065 acre. The forage of the three center rows was weighed for green forage yield; the two outside rows served as guard rows. The treatments were laid out in the completely random block arrangement with four replications, making a total of 12 plots.

The irrigation treatments were initiated after harvesting the plant crop in May 1944. The experiment was ended in August 1946 at which time six crops had been harvested.

A series of growth measurement studies was made in conjunction with the irrigation experiment to evolve a yardstick to serve as a guide for determining the time to irrigate the intermittently irrigated plots, and to study the various phases of growth of koa haole, especially with regard to the best time to harvest so as to get a maximum production of succulent leafy growth of high protein content coupled with the ability to make satisfactory recovery after each harvest.

The following growth measurements were taken at weekly intervals, beginning 5 weeks after the previous harvest and continuing up to the harvest:

1. Stem elongation. Measurements were taken on the main stem from the head of an 8-inch spike, driven alongside the plant to ground level, to the apex of the growing point.

2. Production of new and dry leaves. Production of new leaves was followed from week to week by placing a small tag above the uppermost new leaf produced at the time of each reading. All leaves produced above the tag which had definitely unfurled their leaflets, were counted as new leaves. Dry leaves were counted by tying a piece of cotton twice above the node of the uppermost dropped leaf. A leaf was considered dry when all the leaflets had fallen off. The difference between cumulative new leaf production and dry leaf production was designated as net green leaves.

Ten plants each were taken from duplicate plots from each treatment for growth studies. The pilot plants in each plot were spotted at more or less definite intervals over the entire length of the center row. Additional data on flowering, amount of branching, percentage of leaves, etc., were taken on these pilot plants at the time of harvest.

Green forage yields: Table 7 gives the green forage yields. Because of the well-distributed and apparently adequate rainfall for the normal growth of koa haole during most of the 27 months of study, a marked response to irrigation was noted only in two crops. For the entire period there was no significant difference in yield of green forage between the intermittent and adequate irrigation treatments but both had significantly greater yields than the single irrigation treatment.

The yields of the single irrigation treatment markedly reflect the lack of adequate moisture in the first and sixth crops. Yields of the intermittent irrigation treatment were relatively constant, varying from 5.20 tons to 7.43 tons per acre. In only the first and sixth crops, however, were they markedly greater than those of the single irrigation. In only the first crop did adequate irrigation markedly surpass the intermittent irrigation yields. This unusually high yield was probably due to a desirable combination of ample sunshine, summer temperature, and favor-

TABLE 7. Green forage yield of koa haole produced under three irrigation frequencies; rainfall and number of irrigations per crop.

CROP NO.	NO. OF DAYS OF GROWTH	GROWTH PERIOD	NO. OF IRRIGATIONS PER CROP			RAINFALL COMPUTED ON PER ANNUM BASIS	GREEN FORAGE YIELD IN TONS PER ACRE		
			Single irrigation	Intermittent irrigation	Adequate irrigation		Single irrigation	Intermittent irrigation	Adequate irrigation
						Inches			
1	127	5–16–44 to 9–19–44	1	4	14	8.42	1.93	5.80	10.21
2	146	9–19–44 to 2–12–45	1	4	16	22.18	4.94	6.06	5.84
3	129	2–12–45 to 6–21–45	1	3	11	48.67	7.13	6.93	7.28
4	110	6–21–45 to 10–9–45	1	3	8	24.85	5.78	7.42	6.62
5	149	10–9–45 to 3–7–46	1	3	12	57.32	6.06	6.05	4.77
6	160	3–7–46 to 8–14–46	1	6	19	10.58	1.85	5.20	4.54
Mean per crop	137		1	3.8	13.7	28.67	4.62	6.24	6.54
Mean yield in tons per acre per annum							12.31	16.65	17.45

able soil tilth of the newly prepared field combined with ample moisture. In four of the remaining five crops, yields of this treatment were actually lower than corresponding yields of the intermittent irrigation treatment. The yields of the fifth crop were significantly lower than those of the single irrigation treatment. It seems quite probable that the poor performance of this treatment during the latter part of the experiment was due to excessive moisture.

There was no semblance of relationship between rainfall and forage yields in either the intermittent or adequate irrigation treatments, but in the single irrigation treatment correlation was fair. In the first and sixth crops of the treatment the rainfall was under 11 inches on the per annum basis and the green forage yields were under 2 tons per acre per crop. The increase in the yield of green forage was almost proportionate with an increase in rainfall in the second and fourth crops. The yield increased still further in the third crop with increase in rainfall but the two were not commensurate. With still greater increase in rainfall in the fifth crop the yield dropped somewhat.

Growth measurements: The great variation in, and the apparent adequacy of, rainfall during the greater part of the experiment nullified differences in growth measurement studies throughout most of the experiment. Season also had a pronounced effect. In spite of these disturbing factors, certain broad conclusions may be formulated. Some of the more salient points are summarized below:

1. The considerable differences in the increments of growth measurements between the different crops seem to mirror the effects of seasons. The growth increments of the winter crops were much smaller and were subject to greater fluctuations than those of the summer crops.

2. When the rainfall was low, high correlation was noted between rainfall and the various growth criteria in the single irrigation treatment. Likewise during a dry period, a rapid and high response was noted after each intermittent irrigation treatment.

3. Regardless of treatments there was an invariable drop in the growth increments in the last quarter of the growing period, and in general the drop was greater when the initial growth increments were high.

4. On the basis of weekly gains the following regressions on age in weeks were noted: Stem elongation and production of both new and dry leaves were linear, the former two decreasing with age and the latter increasing with age. The net gain in green leaves was curvilinear, rapid decrease being noted during the early stages of growth, followed by a gradual decrease during the mid-period, and finally by a leveling off toward the end of the crop.

5. In most of the crops, regardless of the treatments, the various growth criteria show relatively slight changes during the growth cycle of a crop. For this reason, it is not possible to formulate any practical growth index for determining the optimum stage of harvesting for the maximum forage production per unit of time of growth. However, our experience with frequency of cutting and observations on the numerous experiments on the management of koa haole indicate that best forage yields are usually obtained when the plants are harvested when they are 4 to 5 feet tall, are approximately 4 months old, and a few of the more advanced plants are in the full-bloom stage.

First crop measurements: Since the rainfall during the growth of the first crop was very meager, response to irrigation treatments was excellent, as reflected in both growth measurements and in the yield of green forage. As the behavior of this crop might well reflect the response of koa haole grown under irrigation during a dry period, the results of the first crop will be presented below in some detail:

During the entire growth period of 127 days, the rainfall was 8.42 inches on the per annum basis. Only during 1 week was rainfall in excess of 1 inch; during 3 weeks it was about 0.2 inch per week, and in the other 14 weeks it was less than 0.2 inch per week. During the 127-day period, the single irrigation treatment received no irrigation after the initial one applied 13 days after the previous harvest. The intermittent irrigation plots received three irrigations and the adequate irrigation plots 16 irrigations.

The recovery of all treatments after the previous harvest was excellent. When the initial growth measurements were taken 6 weeks after the last harvest, the plants were making exceptionally rapid growth. The leaflets were unusually large, being fully three to four times the average size of leaves from well-matured plants. The number of pinnules and the number of leaflets per pinnule progressively increasing correspondingly smaller number of leaflets.

At the time of harvest the leaf size varied with the frequency of irrigation, the number of pinnules and the number of leaflets per pinnule progressively increasing with irrigation frequency although the difference was relatively small. Likewise the size and the total number of leaflets increased with frequency of irrigation.

The stems of the single irrigation plots were decidedly reddish-brown near the apex, but the terminal part of the stems in the other two treatments had the normal greenish color. The stems of the single irrigation treatment were short and willowy but very tough. The central stems produced practically no laterals but most of the secondary stems (small stems produced from the crowns) were alive and much more numerous than in other treatments. In both the intermittent and adequate irrigation treatments, growth was confined to a single central stem and its laterals; secondary stems and some of the lower laterals of the central stem were all dead.

In the single irrigation treatment, even at the time of harvest, the rows were distinct, with considerable space between them. The plants made open, spreading growth and as a result, a considerable number of secondary stems were produced. Due to the continuous dropping of the lower leaves caused by inadequate moisture only a tuft of leaves at the very apex of the central stem was left at the time of harvest. The leaves were definitely wilted throughout the last half of the crop. In both the intermittent and adequate irrigation plots the rows were completely interlocked by the end of 10 weeks of growth so that very little sunlight penetrated to the ground. The single irrigation plots were quite weedy but the plots in the other treatments were essentially weed free.

Preharvest samples were taken for measurements on the relative production of leaves and branches in the different treatments. In marked contrast to the outstanding differences in yield, there was only a slight difference between irrigation treatments in the quality of the harvested forage as measured by percentage leafiness; even the single irrigation treatment fared well. At the time of harvest a moderate number of plants were in bloom. Growth measurements taken on plants in bloom showed no differential behavior from non-flowering plants.

There was a steady and quite sharp decline in stem elongation in the single irrigation plots from the 7th to 13th week of growth, except for a slight increase at 12 weeks which may have been the reflection of 0.21 inch of rainfall which fell during the previous week. A sharp downward break was noted at 13 weeks and thereafter the decline was gradual; stem growth was practically nil at the time of harvest. The results given above are shown graphically in figure 14, together with those of other measurements and the weekly rainfall data.

In the intermittent irrigation treatment three cycles are noted, the changes being noted after each irrigation period. The growth behavior for the first three measurements was practically identical with that of the single irrigation treatment, which was to be expected as the treatments were the same up to this period. The decline in stem elongation was sharp and linear. The rate of stem elongation for the second irrigation period was irregular. Marked response to irrigation was noted in the first measurement, made 6 days after the application of water. Further increase in stem elongation was noted in the next measurement; the next two readings, however, showed a marked decline, particularly the last measurement. A third and final irrigation was given after the eighth measurement. The response to irrigation was again positive for the 3 subsequent weeks but the response was slight. The sharp decline noted at 17 weeks obviously indicated the need of irrigation but since the contemplated harvesting was only a week away no irrigation was given.

The marked drop in stem elongation for the 17th and 18th weeks may also indicate the result of factors other than irrigation, since the plants in the adequate irrigation treatment also showed the lowest increment of growth. A fair number of plants in all treatments were in flower. In most perennial species initiation of flowering is generally accompanied by temporary cessation or slowing up of vegetative growth. It is also possible that because of the long intervals between irriga-

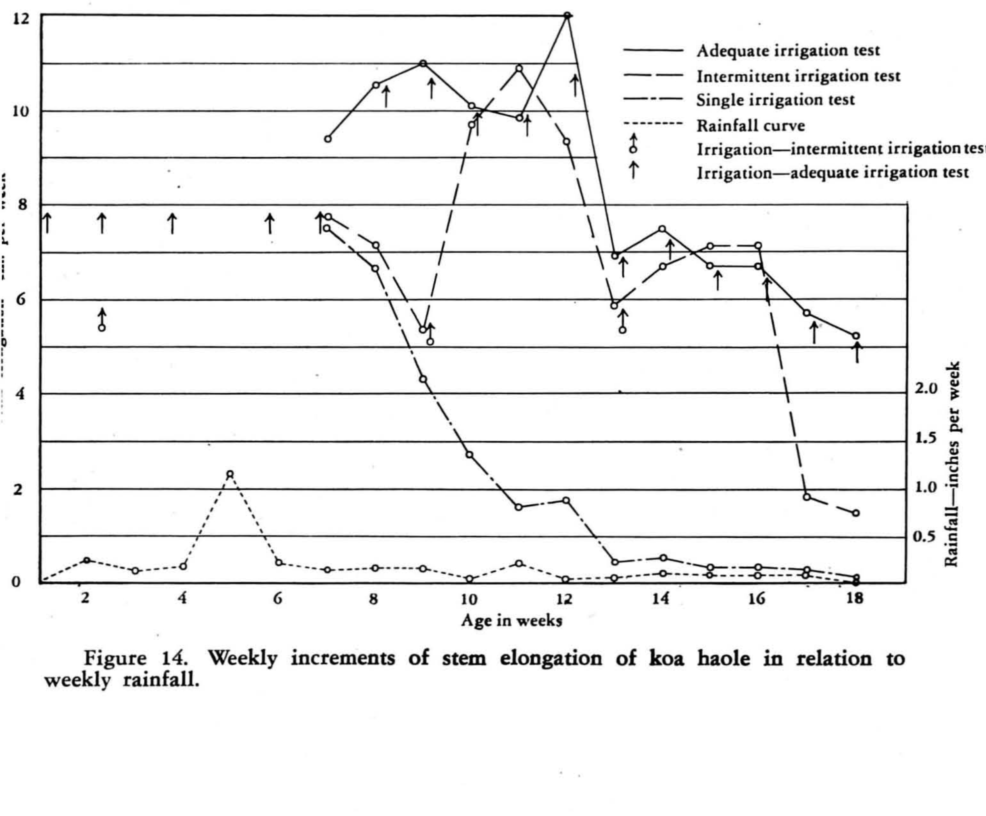


Figure 14. Weekly increments of stem elongation of koa haole in relation to weekly rainfall.

tion there was a slow but gradual depletion of moisture in the sub-soil, which reacted with maturity in reducing the growth rate greatly in the intermittent irrigation treatment.

In two measurements the rates of stem elongation of the intermittent treatment exceeded those of the adequate irrigation treatment. In both instances the greatest increase was noted in the second measurement after each irrigation. Greatly accelerated growth following a period of partial dormancy is frequently found in many plants, particularly in an arid climate. After the plant food reserves are used up, the growth rate returns to normal, in spite of continued favorable growing conditions.

In the adequate irrigation treatment, with the exception of one measurement at 12 weeks, the rate of stem elongation declined steadily after the fourth measurement, at 9 weeks. The rate of decrease appeared to be approximately linear, being 11.055 cm. per week at the fourth measurement and 5.185 cm. for the last measurement. The drop in the rate of stem elongation with advancement in the age of the plants was also noted in the other crops of this treatment. The drop was roughly proportional to the initial growth increments; the larger the initial growth rate the greater the drop as the plants approached maturity. The mean heights of the plants at the time of harvest were 87.90, 139.89, and 160.21 cm. for the single, intermittent, and adequate irrigation treatments, respectively.

The general trend in the production of new leaves was a close replica of stem elongation for all treatments and is shown graphically in figure 15. Statistical analysis of the data showed high correlation between stem elongation and production of

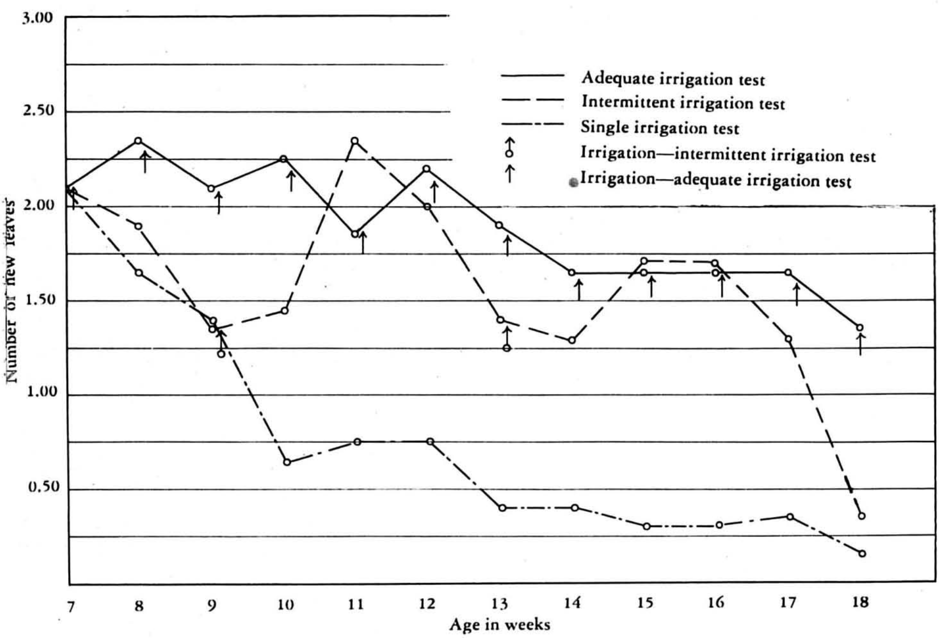


Figure 15. Weekly gain in new leaves of koa haole.

new leaves. The regression was linear, a decrease in stem elongation being accompanied by a proportionate decrease in new leaf production. Likewise the production of dry leaves was found to be inversely correlated with stem elongation.

Discussion and conclusions: The most significant result is the small number of irrigations required to produce a good crop of koa haole. The average number of irrigations, calculated on annual basis, was 36.5 for the adequate irrigation treatment, 10.1 for the intermittent, and 2.7 for the single irrigation per crop. The intermittent irrigation plots produced consistent yields throughout the experiment with an average of less than one irrigation per month. In contrast, Napier grass in an adjoining field required 25 to 30 irrigations per year or one every 12 to 14 days. Thus for full production koa haole required only one-half to one-third as frequent irrigation as the grass crop. Evidently the deep-rooted koa haole makes effective use of moisture at depths essentially unavailable to the grass. Yields of the single irrigation treatment are equally interesting. In four of the six crops, essentially full production was obtained. It is unfortunate that a no-irrigation treatment was not included, but in planning the experiment it was thought that without some irrigation the newly established crop would not survive periodic cutting at ground level in this relatively dry location.

These results suggest the feasibility of growing koa haole as a soilage crop without irrigation in locations where rainfall is entirely too low for production of grass forage. Some idea of the moisture requirements of koa haole may be secured from yields of the single irrigation treatment by assuming the figure of 5-acre inches of water per irrigation or 13.5 inches per year of added water for the 2.7 irrigations. Adding this to the rainfall for the several crops, it may be concluded that rainfall under 25 inches per year, even assuming uniform distribution, is entirely inadequate since the yield, as in the first and sixth crops, was less than 2 tons per crop. Barring poor distribution, 40 inches of rainfall per year would be adequate for fair production. Consistently good yields should result with 50 inches of annual rainfall.

Production of koa haole for cut forage without irrigation would have many advantages. It would materially reduce the cost per ton of forage, permit the use of lands too broken or too steep for effective irrigation, as well as areas for which irrigation water is not available, and permit the more effective use of machinery for production and harvesting by eliminating short rows and irrigation ditches.

The major value of irrigation in areas of moderate rainfall would be the guarantee of forage production during occasional periods of drought. The dairyman would thus have to evaluate this against the higher costs of production and restricted areas available under irrigation. If his feeding schedule could be adapted to seasonal production, koa haole could be produced without irrigation at a nominal cost per ton. The average rainfall per month in a given location would give a fair idea as to the duration of the seasons of production. It could be assumed that all months having a precipitation of about 3½ inches would produce good growth.

OTHER FORAGE LEGUMES

In considering the production of more forage legumes in Hawaii, as well as the specific production of koa haole for forage, the question arises as to the relative merits of legumes, other than koa haole, that have been tried here. Actually, regardless of its value no single legume is adapted to all the varied climates of Hawaii. Koa haole, for example, should not be planted for soilage purposes above altitudes of about 700 feet or in zones with a rainfall in excess of about 65 inches. Hence, for the different combinations of rainfall and altitude a considerable variety of forage legumes is needed.

The need for leguminous crops, particularly for fodder, was recognized by the Hawaii Agricultural Experiment Station at its inception in 1901, and an intensive study was undertaken to test systematically a large number of legumes for their adaptability to Hawaiian conditions and to improve by selection the varieties best suited to different uses. The results of this early work were published in 1911 (*22*). Investigations on various aspects of legumes for green manuring, pastures, forage, and food have continued. A recent check of accession records reveals that well over 300 species and many hundreds of varieties have been tried. These are distributed among about 60 genera, ranging from those common in the temperate zones to the truly tropical species.

The establishment of introduced legumes in Hawaiian pastures has been quite successful. In the cool, moist conditions are six species of *Trifolium,* four of *Lotus,* and two of *Vicia.* In the uplands with a more seasonal climate are four species of *Medicago* and two of *Melilotus.* In the more tropical lowlands, there are six species of *Desmodium* and single species of several other genera.

The history of agricultural development in Hawaii reveals several periods of interest in the growing of legumes in cultivated fields. About 1910, soybeans were raised on a rather extensive scale, mostly for soy sauce and other food products. Soybean production reached a peak of 200,000 pounds per year. About the same time the sugar plantations made numerous trials of leguminous green manuring crops to improve their fields. In the 1920's the pineapple companies made rather extensive use of legumes, principally pigeonpeas, in the crop cycle. A maximum of about 5,000 acres of pineapple fields was planted to legumes (*23*). In early homesteading ventures various types of legumes were tried. Many of the homesteaders, from the mainland United States, attempted a system of crop rotation and feed production in their cultivated fields to conform to accepted mainland practices. Although well-adapted species were found, the growing of annual soilage legumes has never assumed any importance. In comparison with perennial legumes, annuals suffer from increased costs of planting and culture and from erosion on the sloping lands characteristic of most areas in Hawaii. Annual legumes generally produce a lower yield on a yearly basis than do perennials. Also they generally have a definite period of maturity and must be harvested soon thereafter. This involves some form of forage preservation, a practice which has never had wide local acceptance. By 1930 annual legumes had been replaced by alfalfa. This acreage gradually decreased and at present alfalfa, too, is practically nonexistent. The present interest in the growing of koa haole as a soilage crop may indicate a revival of interest in the growing of soilage legumes.

Brief descriptions of the principal forage legumes adapted to Hawaii, both annual and perennial, follow:

ANNUAL LEGUMES

Cowpea (*Vigna sinensis*) has long been one of the ranking forage and green manuring crops of the southeastern states. At its best it outyields most other annual legumes and is particularly valuable on soils too poor for most other crops. It grows well in Hawaii but its susceptibility to aphis, leaf hopper, and pod borer makes it unreliable.

Jackbean (*Canavalia ensiformis*) is a bushy, strong-growing, semi-erect annual with rather coarse woody stems. It produces very large pods with 10 to 14 large seeds in each. It is well adapted to Hawaii, forage yields of 16 to 20 tons per acre being recorded. It has rather low palatability, although Krauss reports that cattle soon acquire a taste for it (*22*).

Velvetbean (*Stizolobium* spp.) is a vigorously growing trailing vine, grown mostly for green manuring or for temporary pasture. The dense matted growth is difficult to harvest and to cure. As the pods constitute a valuable part of the forage, the animals are turned in after the pods have matured, which requires 170 to 200 days. In one test at this Station (*22*) a variety called Lyon bean produced the outstanding yields of 3½ tons of seed and 17 tons of green forage per acre. However, Krauss states that the velvetbean was the least palatable legume discussed in his bulletin (*22*).

Soybean (*Glycine max*) varieties are very great in number. They are grouped according to their use: the seed types, which make a relatively small vegetative growth and are grown primarily for the seed crop; the dual purpose types, which have value both for the forage and the beans; and the forage types, which make the largest vegetative growth and are grown primarily for forage or green manure. Numerous variety trials of each type have been made in Hawaii and occasionally good yields have been obtained. In one test at the Pensacola Branch Station, 20 tons of green forage and 2 tons of beans per acre were secured. The crop is highly sensitive to seasonal changes, however, and yields in most tests have not been encouraging.

Peanut (*Arachis hypogaea*) is an important crop in the southern states, fed as cured hay after the seeds are threshed out, or used for grazing primarily by hogs. It is well adapted to Hawaii and is grown to a limited degree, for food purposes. It would be of considerable use in swine production here since the seeds produce soft pork, which is much preferred by the Oriental population.

Lespedeza (*Lespedeza* spp.) is a legume of great importance in the southern states both as a grazing and as a hay crop. Repeated trials of numerous varieties have been made in many localities in Hawaii but with indifferent success. It has become established in the pastures of some localities but seldom makes sufficient growth to be of importance even as a grazing legume.

Other annual legumes, of importance elsewhere for forage, which have been tested in Hawaii are: bonavist bean (*Dolichos lablab*), mung bean (*Phaseolus aureus*), Florida beggarweed (*Desmodium tortuosum*), wild peabean (*Phaseolus lathyroides*), moth bean (*Phaseolus aconitifolius*), several lupines (*Lupinus spp.*), field peas (*Pisum arvense*), chick pea (*Cicer arietinum*), crotalaria (*Crotalaria* *intermedia*), fenugreek (*Trigonella foenumgraecum*), grass pea (*Lathyrus sativus*), and guar (*Cyamopsis psoraloides*).

PERENNIAL LEGUMES

Past experience seems to have proved that Hawaii, with its year-round growing season, can produce forage more economically from perennial legumes than from annuals. The most important of the perennial forage legumes adapted to Hawaii are, therefore, described in somewhat greater detail.

Alfalfa (*Medicago sativa*) in Hawaii is probably best adapted to the open, sandy soils of some of the coastal flats (Catano series). At the University Farm it was successfully grown in heavy soil types. With sufficient application of lime and phosphates it can be grown in the lateritic types (Low Humic Latosols). Alfalfa has been grown experimentally at altitudes as high as 6,000 feet and experimental plantings indicate that it may be the best of the soilage legumes in the Waimea soil family characteristic of the Waimea Plateau on Hawaii and the upland slopes of Haleakala on Maui.

Part of the reason for the decline in the acreage of alfalfa has been the appropriation for other purposes of the lands in which it was growing. A more basic reason, however, was the excessive cost of production due to hand weeding of the noxious grasses which are ever-present in every alfalfa field, and the primitive, hand methods of culture and of harvesting. Newly developed chemical weedicides have been used recently in alfalfa fields (*4*). These are coming into extensive use in California, and preliminary tests here indicate that they may be equally applicable in Hawaii. With a suitable field layout, mechanical cultivation or chemical sprays to control the weeds, and mechanical harvesting, this crop will deserve careful reconsideration.

Alfalfa has a higher green forage yield than koa haole and can be cut as often as 10 to 12 times a year. The two are about equal in forage value, although there is probably less waste in the feeding of alfalfa. This crop will grow at much higher altitudes than koa haole. It lacks the persistence and ruggedness so characteristic of koa haole. It would require the best and most arable lands and frequent irrigation in most instances. The grower should not plant the crop unless he is equipped with machinery and facilities to mechanize his planting and production completely.

Desmanthus or dwarf koa (*Desmanthus virgatus*). This legume is a native of tropical and subtropical America but is widely distributed throughout the tropics. It is a member of the Mimosa family, which also includes sensitive plant (*Mimosa pudica*) and koa haole. Since Hillebrand (*19*) does not list it, it is considered a more recent introduction than koa haole. Rock (*31*) mentions it as occurring in one locality. It is now a common wayside plant, and because of its prolific seeding habit it is a troublesome weed in cultivated fields. Unlike koa haole it is seldom found in pastures, and is restricted largely to roadsides and unused lots. In appearance desmanthus somewhat resembles koa haole but differs in its slender angular pithy stems, smaller leaflets, and narrow pods.

In the cutting frequency experiment earlier described it was concluded that desmanthus is an acceptable soilage legume. The forage has a lower protein content and is probably less palatable than koa haole. Its climatic requirements are similar to those of koa haole except that it is still more sensitive to temperature and probably should not be planted above 300 feet elevation. Its principal advantage over koa haole is its pithy stems, which permit ready harvesting either by hand or with a power mower.

Pigeonpea (*Cajanus cajan*). The pigeonpea is a native of tropical Asia but because of its seeds, which are used mainly for human food, is now cultivated in many tropical countries. It is sometimes referred to in Hawaii as Puerto Rican bean or pea, probably because of the fondness of the Puerto Ricans for the seeds. Hawaii is the only country in which the pigeonpea is grown principally for forage. Hillebrand (*19*) mentions it as being of early introduction. In 1864, Horace Mann, Jr., and William P. Brigham collected it and found it well naturalized. Until recently the genus *Cajanus* was considered monotypic but recently (*32*) another species has been reported from India.

The pigeonpea is a short-lived perennial with a shrubby habit of growth. It produces a major seed crop once or twice a year. Grazing animals eat principally the pods and the terminal foliage of the branches. For cut forage, the plant is topped at about 2½ feet. These well-leafed and fully podded branches have high nutritive value, with about 40 to 50 percent dry matter and as much as 16 percent crude protein on the dry basis.

The pigeonpea has had considerable vicissitude since its introduction. At the height of its popularity as a grazing crop for beef fattening paddocks, 5,000 acres or more were planted (*22*). The present acreage does not exceed 500. At one time several dairymen grew the crop and hand-topped the forage, which was fed green or dried. None is now grown for that purpose.

The principal reason for the decline is the relatively short effective life of the pigeonpea. Under grazing conditions, it makes vigorous growth during the first year and then gradually declines. After the third year both stand and vigor deteriorate so that the field ordinarily requires replanting at the end of 4 to 5 years. In spite of its comparatively short effective life, several ranchers and dairymen contend that the pigeonpea will produce more milk and finished beef per acre than any other crop. They also feel that pigeonpea stimulates the productivity of accompanying grasses. The acreage for grazing purposes is again increasing.

Use of the pigeonpea as a soilage crop has always been limited because of the high cost of hand-topping. Recent developments in harvesting machines may remove this obstacle, and the ratooning ability of the pigeonpea is being re-investigated. In one test a single harvest of the fully podded tops gave 10 tons of green forage, 4 tons of dry matter, and 800 pounds of crude protein.

It is significant that the pigeonpea is the only perennial legume of any importance in Hawaii to produce an appreciable seed crop. Recent introductions from East Africa have given rise to some selections which appear to have a more "everbearing" seeding habit in contrast to the more seasonal habit of the common strain D.

The pigeonpea has a rather wide range of adaptability. It makes most rapid growth at low elevations but will grow and pod as high as 3,500 feet. The main grazing areas are located above 2,000 feet in Zone C_2. The crop requires moderate moisture. In the higher rainfall zones it makes a vigorous vegetative growth but produces a sparse seed crop and according to the ranchers the animal acceptance is poor. It is seriously affected by protracted drought; with a return of rainfall, the plant does not recover its previous vigor. A dry period following the harvesting of the forage sometimes results in a serious loss of stand. The crop is very tolerant of soil type. It will grow in light- or heavy-textured soils and will tolerate considerable acidity. It should not be planted on thin or eroded types.

The pigeonpea is probably best located in the uplands above about 1,000 feet in Zone C_1, where it can be grown without irrigation, on an extensive scale, and at a low cost. It may remain essentially a grazing species but with suitable harvesting machinery it may serve a useful purpose as a soilage crop. Under such conditions it could well serve as a combination grazing and soilage crop. The pigeonpea lacks the persistence and ruggedness of koa haole, but its adaptability to higher elevations, its proved value for grazing, and the high proportion of seed in the harvested forage should give it a place.

RECENT INTRODUCTIONS

Since Hawaii is pre-eminently a land of pastures, considerable stress has recently been given to the introduction of tropical grazing legumes adapted to the low humid areas. Nearly all legumes originating under such conditions have an inherent tolerance for acid soils with a relatively low level of available plant nutrients. Several very promising species have been found.

Creeping indigo (*Indigofera endecaphylla*) has shown exceptional promise. It is adapted to elevations as high as 3,000 feet. It is fairly drought resistant but its principal use will probably be in the higher rainfall Zones C_1 and D_1. It can apparently be established in much of Zone D_1 without the use of lime or fertilizer. Its decumbent growth habit permits it to grow with the comparatively tall Guinea grass and panicum grass as well as the shorter Dallis and kikuyu grasses.

Tropical kudzu (*Pueraria phaseoloides*) is more temperature sensitive than creeping indigo and probably should not be planted above 1,000 feet. It seems to be well adapted to the acid soils of Zone D_1. It is a natural climber and apparently does best when it is interplanted with a tall grass like Napier grass. The kudzu common to the southeastern states (*Pueraria thumbergiana*) has persisted for many years in several localities, especially at Waimea, Hawaii, at 3,000 feet. Effective growth is limited to a short period during the summer and the total forage production is relatively small.

Kaimi clover (*Desmodium canum*) was first recorded in Hawaii in 1916 (*20*). Since that time it has spread by natural seeding throughout much of Zones C_1 and D_1. Its maximum altitude is probably about 2,000 feet. It spreads by creeping stems which may attain a spread of 15 feet or more in a few years; these prostrate stems send up seeding stems to a normal height of about 12 inches. *Desmodium intotum* and a number of other promising species of this genus are also under trial. All the foregoing species produce seed readily in Hawaii and are easily established by direct seeding.

While normally these legumes would be regarded as grazing species only, preliminary trials indicate that they may also have value for cut forage. Of particular significance are the yields which were secured from pasture mixtures of these legumes and paspalum. For example, periodic harvests of creeping indigo and paspalum yielded 5 tons per crop per acre, of which 66 percent of the harvested forage was creeping indigo. Harvesting of the forage in a pasture during the periods of surplus growth, followed by grazing throughout the remainder of the year, might well become an accepted practice. Recent trials indicate that a standard ensilage harvester equipped with a mower bar unit can be effectively used in cutting such forage in many pasture lands.

TABLE 8. Chemical composition and acre yield of green forage and digestible nutrients of grasses and legumes grown for dairy feed.

FORAGE	YIELD OF GREEN FORAGE PER ACRE PER ANNUM	CHEMICAL COMPOSITION OF GREEN FORAGE ON GREEN BASIS		DIGESTIBLE NUTRIENTS IN GREEN FORAGE		YIELD PER ACRE PER ANNUM		NUTRITIVE VALUE
		Crude protein	Dry matter	Protein	Total	Digestible crude protein	Total digestible nutrients	
	Tons	*Percent*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	1:
Napier grass*	70.9	1.03	21.1	0.55	12.5	780	17,727	21.74
Panicum grass*	53.2	1.78	28.0	1.07	16.3	1,139	17,285	14.18
Koa haole†	26.0	6.62	29.2	4.30	16.7	2,236	8,695	2.89
Alfalfa*	37.5	4.06	19.9	3.00	11.8	2,249	8,863	2.94
Desmanthus†	24.0	4.33	32.0	2.65	17.4	1,272	8,352	5.57
Pigeonpea tops*	25.0	9.41	49.7	6.49	33.6	3,245	16,780	4.17

* Data from *Roughages for Dairy Cattle in Hawaii* by L. A. Henke. Hawaii Agr. Expt. Sta. Bul. 92 (1943).

† Yield data and chemical composition taken from the 4× treatment in the frequency of cutting experiment at Pensacola Branch Station recorded in this bulletin. Digestibility coefficients as determined by Work (5, 6) were used to convert these data to digestible nutrients.

RELATIVE MERITS OF PERENNIAL LEGUMES

Table 8 gives the green forage yield, chemical composition, yield of digestible crude protein, and total digestible nutrients of the four perennial soilage legumes previously discussed. Data were insufficient for the inclusion of creeping indigo, tropical kudzu, and Kaimi clover. Yield data for pigeonpea and alfalfa came from the University Farm and those for koa haole and desmanthus from the Pensacola Branch Station. These comparative yields should be considered as suggestive only, since location, cultural practices, and age of the planting have a very profound effect on actual yields obtained.

The data show koa haole and alfalfa to be closely comparable as to the acre yield of digestible crude protein and total digestible nutrients. Desmanthus is obviously lower in digestible protein but is slightly higher than the other two in total digestible nutrients. Pigeonpea is outstandingly high in both but has a wider nutritive ratio than alfalfa and koa haole. In considering the relative merits of these legumes the dairymen should also keep in mind their differences in adaptability, persistence, and cultural requirements.

Pigeonpea is worthy of consideration because of its high yields during the first year of production and because it is the only legume which produces a sizable amount of seed. It has the further virtue of adaptability to elevations of 2,000 feet or more, and it has proved value as a grazing legume. Its short productive life, especially under periodic topping, is a limiting factor. It should not be planted for the latter purpose unless the dairyman has adequate facilities for land preparation, seeding, and mechanical harvesting.

Desmanthus is an acceptable soilage legume. It yields well at least during the first 2 years, matures early, and is easy to harvest by hand or with a power mower. In comparison with koa haole, it is less rugged, requires more weeding and care, and gradually decreases in yield with increasing age. It is a temperature-sensitive crop and should not be planted above 300 feet altitude.

Alfalfa, like the pigeonpea, has a wide range of adaptability to altitude and can be grown at elevations far higher than those suitable for koa haole and desmanthus. It yields well in Hawaii for 2 or 3 years after planting and can be cut more frequently than the other legumes. It is, however, more exacting in its soil requirements than our tropical legumes. Its lack of persistence and susceptibility to weed infestation present serious limitations unless the dairyman is fully equipped to mechanize all operations of replanting, weed control, and harvesting.

Koa haole, while not outstanding as to yield, is rugged, persistent, and able to withstand weed infestation, which should appeal to the dairymen of Hawaii. Once established it requires little more field care than does Napier grass. Its low moisture requirements and ability to recover after a drought extend its usefulness to lands not suited to the other legumes. By complete mechanization of all cultural and harvesting operations with machinery already developed, production costs should be at a minimum. Little or no fertilizer is required and infrequent irrigations suffice. Its use, however, is restricted to elevations below about 700 feet and in areas with not more than about 65 inches of annual rainfall.

FUTURE PROSPECTS OF FORAGE LEGUMES

Most dairymen, particularly on Oahu, restrict their forage production to grasses only; legumes play an unimportant part. Napier grass under irrigation predominates in the drier leeward locations, and panicum grass, without irrigation, on the wet windward sides of the Islands. The harvested forage of these two grasses is of relatively poor quality, especially as to the percentage of digestible protein. Napier grass, for example, contains only 0.55 percent digestible protein compared with 4.30 percent in koa haole; the total acre yield of digestible protein from Napier grass is only about one-third that from koa haole (table 8).

The feeding of this coarse grass roughage to dairy animals requires the use of relatively large amounts of supplemental concentrates, particularly protein. Henke (*16*) states that Napier grass provides only 13 percent of the protein and 42 percent of the total nutrients required daily for a dairy animal producing 22.3 pounds of milk. A similar weight of koa haole provides 96 percent of the protein and 55 percent of the total nutrients required. The latter forage permits the elimination or material reduction in the amount of high-priced protein concentrate needed. As a comparison with mainland practices, Moore states (*33*) that for most economical production of milk under average conditions 75 to 80 percent of the nutrients fed must come from roughage.

One reason for the local preference for grass forage is the greater production of total digestible nutrients per acre (table 8). Napier grass produces nearly 18,000 pounds, which is double the amount produced by the legumes. The only exception is pigeonpea, and here the data are for the first year only. Another important reason for the dairymen's preference for these perennial grasses is the relative ease of production. Once established, Napier grass will persist indefinitely with no weeding, cultivation, or other care except irrigation and fertilization. Because of this, few dairymen own field tractors, drills, cultivators, or other field equipment. In brief, the case against the production of forage legumes is that they require more land and greater care.

Most dairies would find it difficult or impossible to increase the area available for forage production in their present locations. Several alternates are possible. It might be feasible for some dairies to move to areas where more land is available. Forage might be produced at locations somewhat distant and transported to the dairy barns. Production of milk on the outside islands and shipment to Oahu by airplanes or fast boats has been considered and some shipments have been made.

Improved techniques and harvesting may have important effects on forage production. The corn binder has proved both efficient and durable in the harvesting of koa haole. More recently, an ensilage harvester has been modified to harvest Napier grass, panicum grass, and koa haole. Advances may be expected in other lines of production, weed control, and preservation. Increased mechanization should materially reduce the costs of forage production. The effective use of most field machinery generally increases with the size of the fields and amount of forage harvested per day. Small dairies may thus find it more economical to pool their forage production or to purchase it from a larger producer.

FUTURE PROSPECTS OF FORAGE LEGUMES

Most dairymen, particularly on Oahu, restrict their forage production to grasses only; legumes play an unimportant part. Napier grass under irrigation predominates in the drier leeward locations, and panicum grass, without irrigation, on the wet windward sides of the Islands. The harvested forage of these two grasses is of relatively poor quality, especially as to the percentage of digestible protein. Napier grass, for example, contains only 0.55 percent digestible protein compared with 4.30 percent in koa haole; the total acre yield of digestible protein from Napier grass is only about one-third that from koa haole (table 8).

The feeding of this coarse grass roughage to dairy animals requires the use of relatively large amounts of supplemental concentrates, particularly protein. Henke (*16*) states that Napier grass provides only 13 percent of the protein and 42 percent of the total nutrients required daily for a dairy animal producing 22.3 pounds of milk. A similar weight of koa haole provides 96 percent of the protein and 55 percent of the total nutrients required. The latter forage permits the elimination or material reduction in the amount of high-priced protein concentrate needed. As a comparison with mainland practices, Moore states (*33*) that for most economical production of milk under average conditions 75 to 80 percent of the nutrients fed must come from roughage.

One reason for the local preference for grass forage is the greater production of total digestible nutrients per acre (table 8). Napier grass produces nearly 18,000 pounds, which is double the amount produced by the legumes. The only exception is pigeonpea, and here the data are for the first year only. Another important reason for the dairymen's preference for these perennial grasses is the relative ease of production. Once established, Napier grass will persist indefinitely with no weeding, cultivation, or other care except irrigation and fertilization. Because of this, few dairymen own field tractors, drills, cultivators, or other field equipment. In brief, the case against the production of forage legumes is that they require more land and greater care.

Most dairies would find it difficult or impossible to increase the area available for forage production in their present locations. Several alternates are possible. It might be feasible for some dairies to move to areas where more land is available. Forage might be produced at locations somewhat distant and transported to the dairy barns. Production of milk on the outside islands and shipment to Oahu by airplanes or fast boats has been considered and some shipments have been made.

Improved techniques and harvesting may have important effects on forage production. The corn binder has proved both efficient and durable in the harvesting of koa haole. More recently, an ensilage harvester has been modified to harvest Napier grass, panicum grass, and koa haole. Advances may be expected in other lines of production, weed control, and preservation. Increased mechanization should materially reduce the costs of forage production. The effective use of most field machinery generally increases with the size of the fields and amount of forage harvested per day. Small dairies may thus find it more economical to pool their forage production or to purchase it from a larger producer.

Greater use of pastures for milk production is being considered. Hawaii, with its year-round growing season, has many natural advantages over the temperate zones in the use of pastures. Good pastures of succulent grasses and legumes can provide an appreciable part of the total feed requirements for milk production, generally at a lower cost than by the use of harvested forage. The practice of grazing would permit the use of land not well suited to the production of soilage crops, particularly in the wetter zones. In the lowlands, where most of the dairies are presently located, the planting of koa haole in the drier zones and of creeping indigo or Kaimi clover, together with nutritious grasses in the higher rainfall areas, should provide pastures of excellent quality.

LITERATURE CITED

(1) AKAMINE, ERNEST K.
1942. METHODS OF INCREASING THE GERMINATION OF KOA HAOLE SEED. Hawaii Agr. Expt. Sta. Cir. 21, 14 pp.

(2) BYERS, HORACE G., MILLER, JOHN T., WILLIAMS, K. T., and LAKIN, H. W.
1938. SELENIUM OCCURRENCE IN CERTAIN SOILS IN THE UNITED STATES WITH A DISCUSSION OF RELATED TOPICS. U.S.D.A. Tech. Bul. 601, 75 pp.

(3) HANCE, FRANCIS E.
1938. SELENIUM—I. Hawaii. Planters Rec. 42:197–210.

(4) HARVEY, W. A., and RIDDLE, O. C.
1946. CONTROLLING ALFALFA WEEDS WITH CHEMICAL SPRAYS. Calif. Agr. Col. [Davis] Div. Bot., 7 pp.

(5) HAWAII AGRICULTURAL EXPERIMENT STATION
1938. DIGESTIBILITY OF HAWAIIAN FEEDING STUFFS. Hawaii Agr. Expt. Sta. Rpt. 1938:70–71.

(6) ———
1940. DIGESTIBILITY OF HAWAIIAN FEEDS. Hawaii Agr. Expt. Sta. Rpt. 1940:27–28.

(7) ———
1943. SOILAGE CROPS. Hawaii Agr. Expt. Sta. Rpt. 1940–1942:72–73.

(8) ———
1943. RABBIT FEEDS. Hawaii Agr. Expt. Sta. Rpt. 1940–1942:41.

(9) ———
1945. STUDIES IN THE UTILIZATION OF KOA HAOLE. Hawaii Agr. Expt. Sta. Rpt. 1942–1944:57–58.

(10) ———
1947. ROUGHAGES FOR DAIRY COWS. Hawaii Agr. Expt. Sta. Rpt. 1944–1946:35–36.

(11) ———
1947. KOA HAOLE AS A ROUGHAGE FOR NON-RUMINANTS. Hawaii Agr. Expt. Sta. Rpt. 1944–1946:46–47.

(12) ———
1947. MIMOSINE CONTENT OF KOA HAOLE. Hawaii Agr. Expt. Sta. Rpt. 1944–1946:51.

(13) ———
1948. MIMOSINE STUDIES. Hawaii Agr. Expt. Sta. Rpt. 1946–1948:55.

(14) ———
1948. KOA HAOLE MEAL AS A SUBSTITUTE FOR ALFALFA MEAL. Hawaii Agr. Expt. Sta. Rpt. 1946–1948:145–147.

(15) ———
1948. KOA HAOLE ROUGHAGE AS A SUBSTITUTE FOR OIL CAKE MEALS. Hawaii Agr. Expt. Sta. Rpt. 1946–1948:38–39.

(16) HENKE, L. A.
1943. ROUGHAGES FOR DAIRY CATTLE IN HAWAII. Hawaii Agr. Expt. Sta. Bul. 92, 29 pp.

(17) ———
1945. PROTEIN SOURCES AND SUPPLEMENTS FOR DAIRY COWS IN HAWAII. Hawaii Agr. Expt. Sta. Bul. 95, 21 pp.

(18) ——— WORK, S. H., and BURT, A. W.
1940. BEEF CATTLE FEEDING TRIALS IN HAWAII. Hawaii Agr. Expt. Sta. Bul. 85, 37 pp.

(19) HILLEBRAND, W.
1888. FLORA OF THE HAWAIIAN ISLANDS: A DESCRIPTION OF THEIR PHANEROGAMS AND VASCULAR CRYPTOGAMS. [Annotated and published after author's death by W. F. Hillebrand.] 673 pp., illus. London and New York.

(20) HOSAKA, E. Y.
1945. KAIMI SPANISH CLOVER FOR HUMID LOWLAND PASTURES OF HAWAII. Hawaii Agr. Expt. Sta. Cir. 22, 8 pp.

(21) ——— and RIPPERTON, J. C.
1944. LEGUMES OF THE HAWAIIAN RANGES. Hawaii Agr. Expt. Sta. Bul. 93, 80 pp., illus.

(22) KRAUSS, F. G.
1911. LEGUMINOUS CROPS FOR HAWAII. Hawaii Agr. Expt. Sta. Bul. 23, 31 pp., illus.

(23) ———
1932. THE PIGEON PEA (CAJANUS INDICUS). ITS IMPROVEMENT, CULTURE AND UTILIZATION IN HAWAII. Hawaii Agr. Expt. Sta. Bul. 64, 64 pp., illus.

(24) MORRISON, F. B.
1937. FEEDS AND FEEDING. Ed. 20, 1050 pp., illus. Ithaca, New York.

(25) MCCLELLAND, C. K.
1915. GRASSES AND FORAGE PLANTS OF HAWAII. Hawaii Agr. Expt. Sta. Bul. 36, 43 pp., illus.

(26) OCHSE, J. J., in collaboration with VAN DEN BRINK, R. C. BAKHUIZEN.
1931. VEGETABLES OF THE DUTCH EAST INDIES. Dept. Agr. Ind. and Commerce of the Netherlands East Indies, Buitenzorg, Java. 1005 pp., illus.

(27) PATERSON, D. D.
1944. THE PROVISION OF ANIMAL FODDER IN TROPICAL AND SUB-TROPICAL COUNTRIES. Imp. Bur. Pastures and Forage Crops [Aberystwyth, Wales], Bul. 31, Part 1, 84 pp.

(28) PENDLETON, R. L.
1934. PHILIPPINE EXPERIENCE IN REFORESTATION WITH IPIL-IPIL AND ITS APPLICATION TO CONDITIONS IN KWANTUNG PROVINCE, CHINA. Lingnan Sci. Jour. 13:215–224.

(29) PERKINS, J.
1907. THE LEGUMINOSAE OF PUERTO RICO. U. S. Natl. Mus., Contrib. U. S. Natl. Herbarium 10(4):133–220.

(30) RIPPERTON, J. C., and HOSAKA, E. Y.
1942. VEGETATION ZONES OF HAWAII. Hawaii Agr. Expt. Sta. Bul. 89, 60 pp., illus.

(31) ROCK, J. F.
1920. THE LEGUMINOUS PLANTS OF HAWAII. 234 pp., illus. Honolulu, Hawaii.

(32) SINGH, D. N., and others.
1942. A NEW SPECIES OF CAJANUS. Indian Jour. Agr. Sci. 12:779–784.

(33) UNITED STATES DEPARTMENT OF AGRICULTURE
1948. DAIRY CATTLE MUST HAVE GOOD FORAGE. Grass—The Yearbook of Agriculture 1948, 120–126. Washington, D. C.

(34) UNIVERSITY OF HAWAII AGRICULTURE DEPARTMENT
1929. KOA HAOLE AS A FEED FOR DAIRY CATTLE. Hawaii Univ. Quart. Bul. 8(4):11.

(35) YOSHIDA, RUTH
1945. A CHEMICAL AND PHYSIOLOGICAL STUDY OF THE NATURE AND PROPERTIES OF LEUCAENA GLAUCA (KOA HAOLE). Proc. Hawaii. Acad. Sci. 1943–1945, p. 5.